U.S. DEPARTMENT OF COMMERCE
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PB-253 049

THE IMPACT OF INCREASED ELECTRIFICATION ON AIR QUALITY FOR THREE SELECTED REGIONS

TRW/Environmental Services

PREPARED FOR
Environmental Protection Agency

January 1976

CONTRACT NO. 68-02-1905

JANUARY 1976

PB 253 049

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By

H.S. Goodman
J.R. Avery
J.L. Midler

TRW ENVIRONMENTAL SERVICES
ONE SPACE PARK
REDONDO BEACH, CALIFORNIA 90278

Project Officer
Mr. Richard Livingston
Environmental Protection Agency
Office of Planning and Evaluation
Washington, D.C. 20460

Prepared for
ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C.

TRW / TRANSPORTATION AND ENVIRONMENTAL ENGINEERING OPERATIONS

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SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA PAGE	1. Report No.	2.	3. Recipient's Accession No. PB-253 049
4. Title and Subtitle: The Impact of Increased Electrification on Air Quality For Three Selected Regions			5. Report Date: January 1976 6.
7. Author(s): H. S. Goodman, J. R. Avery, J. L. Midler			8. Performing Organization Rept. No.
9. Performing Organization Name and Address: TRW Environmental Engineering Division, One Space Park, Redonco Beach, California 90278			10. Project/Task/Work Unit No. 11. Contract/Grant No. Contract # 68-02-1905
12. Sponsoring Organization Name and Address: Office of Planning and Evaluation, Environmental Protection Agency, Washington, D.C. 20460			13. Type of Report & Period Covered: Final 14.

15. Supplementary Notes

16. Abstracts

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17. Key Words and Document Analysis. 17a. Descriptors

Increased electrification, impact on regional air quality, forecasts of regional energy supply, alternative fuel uses, reduced emissions.

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

PRICES SUBJECT TO CHANGE

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 114
i.	20. Security Class (This Page) UNCLASSIFIED	22. Price 5.50-2.25

*U.S. GOVERNMENT PRINTING OFFICE: 1974 582-413/67 1-3

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ABSTRACT

Increased electrification has emerged as a potential option for decreasing our reliance on imported crude oil and as a strategy for reducing emissions. The results from Project Independence Blueprint have indicated that the substitution of domestic coal and nuclear power for imported oil and conservation represent the two most promising near term approaches to our current energy crisis. One of the fundamental concerns of employing a domestic fuel substitution strategy involves its impact on regional air quality patterns.

The purpose of this study was to examine the impact of increased electrification on air quality using existing models and data bases for three candidate regions -- Los Angeles, Denver and St. Louis. Forecasts of regional energy supply and demand were developed in order to estimate the potential for greater electrical end use substitution. The analysis predicted the changes in emission and air quality distributions as a result of various degrees of electric energy usage and alternative fuel mixes.

Results from the analysis indicated that increased electrification would have a small but positive effect on ambient air quality levels in these regions. Care should be exercised, however, in extrapolating these results to other regions. The impact of increased electrification on air quality may be even more promising in regions where petroleum products and coal rather than natural gas constitute the primary fuel source. Additional analysis is required to better characterize the effects of this strategy on a wider spectrum of regions.

This report was submitted in fulfillment of Project No. 68-02-1905 by TRW, Inc., under the sponsorship of the Environmental Protection Agency. Work was completed as of 15 October 1975.

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SECTION I

CONCLUSIONS

Results from the case analysis indicated that increased electrification will have a small but not insignificant impact on ambient air quality inside the study regions. Specific study findings are highlighted below:

- Increased electrification has its greatest impact on oxidant air quality. The reductions in oxidant air quality due to electrification was on the order of 18 percent for Los Angeles and 25 percent and 20 percent for Denver and St. Louis, respectively, Table 1.

- SO_2 concentrations are predicted to decrease slightly relative to the baseline for Los Angeles and Denver and remain virtually unchanged for St. Louis as a result of additional electrical energy end use. The baseline forecast for Denver shows a 33 percent increase in average SO_2 concentrations over the twenty year period. This can be attributed directly to the increased use of coal-fired power plants planned for the Denver area.

- NO_2 concentrations due to increased electrification are estimated to decrease marginally for all three regions. Baseline forecasts indicate a significant reduction in NO_2 for Los Angeles (-16%) and a substantial increase in Denver (+29%) compared to current levels. The former is the result of introducing new vehicles with lower emissions while the latter reflects the increased use of coal-fired power plants.

- Particulate air quality is forecasted to improve somewhat as a result of increased electrification. This is the direct result of substituting electrics for particulate generating IC powered vehicles. The largest change, approximately a 17 percent improvement in air quality, occurred in Los Angeles. The projected increase in baseline particulate air quality in Denver, approximately 4 percent did not correspond to the dramatic rise in SO_2. These results are due in part to the substitution efforts of electrics.

- Shifts in the spatial distribution of NO_2, SO_2 and particulate air quality were observed over the 20 year period. This is the direct result of ongoing control strategies, changes in driving patterns and new power plant additions.

- Total energy consumed within each region is forecasted to increase as a result of electrification. The reduction in energy consumption in transportation due to the introduction of electrics is more than offset by the increased use of electrical energy in the residential/commercial sector. The average increase in total energy consumption by 1995 are forecasted at 11 percent, 8 percent and 15 percent for Los Angeles, Denver and St. Louis, respectively.

- Dramatic increases in the use of electrics in the study regions will not result in a proportional improvement in air quality. This can partially be attributed to the relatively small reduction in emissions achieved by substituting electric vehicles for privately owned conventionally powered vehicles.

- The impact of increased electrification on air quality in regions where natural gas usage is relatively small may be more significant. The substitution of electric energy in coal and petroleum consuming regions may represent an important energy and environmental control strategy of the future.

- The utilizing of linear rollback methodologies in estimating oxidant air quality may be inadequate. The use of oxidant relationships involving both hydrocarbons and oxides of nitrogen may be necessary for determining the full impact of electrification on OX.

TABLE 1. SUMMARY OF AIR QUALITY IMPACTS

	OXIDANT	NO_2	SO_2	TSP
BASELINE	PERCENT INCREASE* IN CONCENTRATIONS, 1975-1995*			
Los Angeles	-45	-16	+ 2	+ 2
Denver	-10	+29	+33	+ 4
St. Louis	- 8	- 6	0	+ 9
ELECTRIFICATION	PERCENT IMPROVEMENT OVER BASELINE, 1995			
Los Angeles	18	2	7	17
Denver	25	5	6	1
St. Louis	20	2	1	8

*A negative percentage indicates a reduction in pollutant concentrations

SECTION II

RECOMMENDATIONS

A number of specific recommendations have emerged as the result of this study. They can best be viewed in a twofold context:

- METHODOLOGICAL REFINEMENTS -

  Those that are directed towards improving the technical estimates associated with the impact of increased electrification.

- FURTHER RESEARCH -

  Those that focus on issues requiring further clarification before final judgment can be made.

Each of these two classes of recommendations will be treated in turn.

METHODOLOGICAL REFINEMENT

- The appropriateness of utilizing the Los Angeles derived VMT relationship should be investigated. Region specific relationships should be developed if necessary.

- Effective methods in comparing air quality concentration levels for alternative scenarios should be developed. The method used in this study was extremely rudimentary and could lead to biased results.

- The capital and operating costs associated with varying degrees of electrification should be developed. This type of data is necessary for determining the "optimal" level of increased electrification on a region by region basis.

- The sensitivity of key model assumptions and data should be evaluated. Additional data collection should be undertaken as indicated by the analysis.

- The need for utilizing more complex OX relationships involving both reactive hydrocarbons and oxides of nitrogen should be assessed. The impact of increased electrification on oxidant air quality should then be evaluated using the most appropriate oxidant models.

FURTHER RESEARCH

This analysis was designed to evaluate the gross impacts of electrification on air quality. A more extensive evaluation utilizing the results from this study should be initiated. Specific tasks should include:

- The inter-regional effects of increased electrification should be ascertained. The air quality implications of remote site electrical power generation must be clearly understood before embarking on a large scale effort.
- The impact on fuel prices of alternative electrification strategies should be investigated. Region specific fuel price elasticities need to be synthesized.
- The technological feasibility of increased electric end use substitution needs to be better defined. Selected demonstration programs should be undertaken.
- The socio-economic implications of increased electrification need to be characterized on both a regional and national basis. Data on population, income and employment shifts are essential in developing a better understanding of these strategies.
- Additional regions should be identified for possible analysis. The expansion of the data base to incorporate other regions will aid in obtaining a more comprehensive picture on the potential role of increased electrification. In particular, regions where petroleum products and coal are the primary source of energy should be evaluated using the methodology outlined in this study.
- The impact of increased electrification on CO emissions and air quality should be analyzed for each of the three regions. An alternative air quality model (e.g., APRAC-1A) will be required to undertake this assessment.
- The effect of industrial electrification on regional air quality should be examined. Several alternative industrial electrification scenarios should be developed.
- The temporal dimensions of increased electrification need to be evaluated. The potential for generation scheduling should be analyzed for each region.
- Nuclear electrification scenarios for the post-1975 era should be studied. The results should be contrasted with the current data base.

SECTION III

INTRODUCTION

The shift to domestic energy resources through increased electrification has emerged as a potential option for decreasing our reliance on imported crude oil through the remainder of this century. The results from Project Independence Blueprint have indicated that the substitution of coal and nuclear power for imported oil and gas and conservation represent the most promising near term approaches to our current energy crisis. One of the fundamental concerns of employing a domestic fuel substitution strategy involves its impact on regional air quality.

The increased use of electric power vis-a-vis direct oil and gas consumption could substantially reduce the number of area source emitters (both mobile and stationary) within a given region. Instead, regional emissions would be generated at a few point sources which could be more easily controlled or ameliorated through remote siting. The introduction of electrics into the vehicle population and the move towards "all electric" homes appear as the two most likely strategies for implementing increased electrical usage. The determination and selection of the optimal degree of electrification with respect to these strategies is confounded by a series of complex technical, socioeconomic and environmental interactions.

The primary objective of this study was to examine the impact of increased electrification on air quality using existing models and data bases for three candidate regions -- Los Angeles, Denver and St. Louis. Forecasts of regional energy supply and demand were developed in order to estimate the potential for greater electrical end use substitution. The analysis predicted the changes in emissions and air quality distributions as a result of various degrees of electric energy usage and alternative fuel mixes.

STUDY PURPOSE

A number of studies have examined various aspects of electric power generation vis-a-vis fuel substitution and air quality [4], [19], [51]. Results from these studies, however, only provide partial insights into the potential for increased electrification in terms of national energy and environmental policy.

This analysis was designed specifically to focus on the issue of the impact of intensive electrical end use on air quality in a case study format. Specific study objectives were:

- To predict emissions and air quality trends as a function of energy end use
- To measure the regional implications of increased electrification
- To estimate shifts in fuel usage patterns as a function of increased electrification
- To evaluate alternative electrification end use scenarios over a 20-year period

METHODOLOGICAL APPROACH

Figure 1 highlights the methodological approach used in assessing the impact of increased electrification on air quality. The first step in the process involves the characterization of the regional sites. This includes a description of current environmental, energy and demographic conditions. Next, projections of energy supply and demand for each region are developed over a 20-year period. These forecasts, along with projections of fuel distribution by sector, serve as inputs to the regional emission simulator. The regional simulator was used to develop the spatial distribution of HC, CO, NO_x, SO_x, and TSP emissions for both the baseline and electrification scenarios. This data provides the basis for estimating NO_2, SO_2, TSP and oxidant air quality concentrations. This same process was repeated when examining the impacts of alternative electrification scenarios.

Energy Projections

Any meaningful analysis of the consequences of changes in energy end use over the next 20-years depends on an accurate characterization of

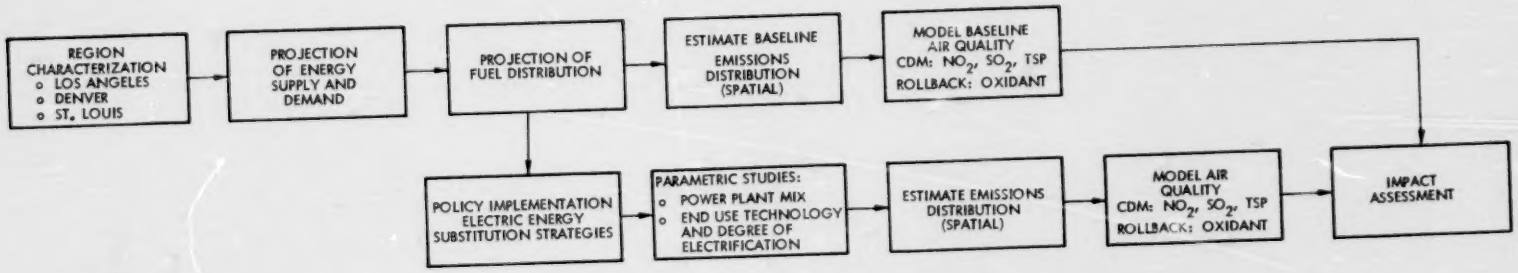


Figure 1 Schematic of Study Methodology

projected energy supply and demand, both for current anticipated trends and for alternative policies such as intensive electricity substitution. Projections of regional energy supply and demand were developed from a composite analysis of several current forecasts. Because of time restrictions, no direct modelling was employed in developing these forecasts. Estimates on the rate of electrical end use substitution were also derived from existing data. The sensitivity of alternative baseline energy forecasts and rates of technological substitution need to be assessed.

Emission Inventories

An essential prerequisite to the forecasting of air quality with atmospheric diffusion simulators consists of the specific identification and quantification of pollutant emissions. An existing set of emission data for each region provides the basis for developing a spatial emission inventory. These data bases were updated using current fuel consumption figures and more recent inventory data. This information was input into TRW's Emission Simulator Model (ESM) which establishes the grid locations and allocates the emissions geographically among the grid squares.

ESM is a general computer model which calculates spatial emission rate distributions for a given regional context. The required inputs are traffic VMT data, power plant locations and emission rates, industrial locations and emission rates and area source locations and emission rates. These input parameters are reduced to localized emissions and distributed into a user designated uniform grid system. Output from ESM has been made compatible with CDM along with other atmospheric models.

Air Quality Predications

The Climatological Dispersion Model (CDM) was used in predicting NO_2, SO_2 and TSP air quality for the three regions. CDM determines long term (seasonal or annual) quasi-steady state pollutant concentrations at any ground-level receptor using average emission rates from point and area sources and a joint frequency distribution of meteorological conditions (see [22] for details). Modifications were made to the basic CDM package to accomodate multiple receptor points for air quality contours to

facilitate a better understanding of the output formats. CDM suffers from an inability to account for topographical features and atmospheric chemistry.

Oxidant air quality was estimated using the upper limit curves depicted in Figure 2. These functions relate maximum 1-hour oxidant concentrations to region-wide nonmethane hydrocarbon. Estimates of air quality for Los Angeles were made using the Schuck-Papetti curves [31] and for St. Louis and Denver, the Barth curve [30]. The air quality data for utilizing this technique neglects the spatial distribution of emissions and the resultant air quality. It should be noted that the former is much more sensitive to changes in hydrocarbon emissions over the range of interest and, therefore, will yield more dramatic results.

SELECTION OF STUDY REGIONS

A case study approach was used in assessing the impact of intensive electricity end use on air quality. The selection of specific study regions was made according to the following criteria:

- Different levels of mobile, area and stationary source emission contributions
- The magnitude of the pollution problem in the region
- The spatial distribution of emission sources and air quality levels
- The distribution of emissions for the fuel use sectors
- The degree to which emissions from mobile and stationary fuel combustion sources contribute to the overall regional emissions (reflecting the potential leverage of fuel use changes for affecting air quality)
- The degree of emission control achieved in the region and the projected controls expected
- The availability and reliability of relevant data characterizing the air pollution problems in the region

Experience from related studies [45], [52], [53] has indicated that, based on the above criteria, substantial variations exist between a number of potential study areas. Analysis of these variations is essential for providing a broad based assessment of electrification impacts.

Utilizing the above criteria, Los Angeles, Denver and St. Louis were selected for in-depth analyses. These three regions provided a good

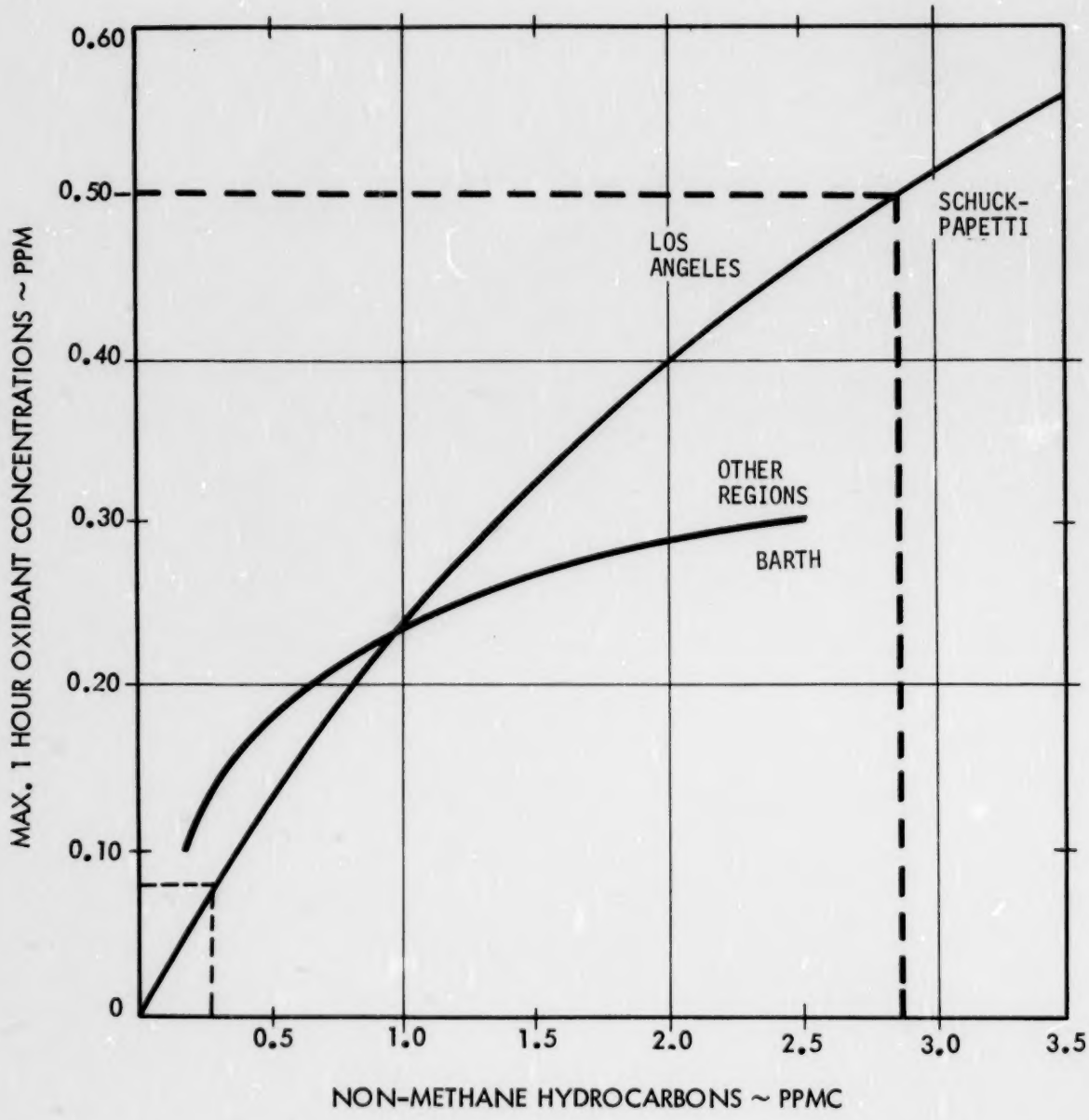


Figure 2. Upper Limit Relationship
Of Oxidant and Nonmethane Hydrocarbons

contrast, both in terms of energy usage and air quality characteristics. Figures 3, 4 and 5 illustrate the Los Angeles, Denver and St. Louis study regions, respectively. The location of major power generation facilities are depicted for ready reference.

The geographical context of the regional study was derived according to data availability and compatibility, computer model capacity limitations and conformity with basic study objectives. In Los Angeles, for example, the unpopulated and remote areas of the AQMA were excluded from the grid system. For St. Louis, the study region was limited by the availability of traffic data and therefore, several major facilities providing power to St. Louis were located outside the study region. This type of decision will obviously have a significant impact on the results.

BASIC ASSUMPTIONS AND STUDY LIMITATIONS

Because of both time and resource limitations, a number of facilitating assumptions were adopted to insure that the analysis could be completed within the required 3-month time period. These included:

- Analysis was designed to look at "most favorable case"
- All new planned additions in capacity by the utilities are located outside the study regions.
- All increased electrical power generated within the region to meet electrification requirements is assigned proportionally to existing plants
- Generating capacity projections are based on surveys of utility companies in study regions
- CDM provides an adequate description of dispersion of NO_2, SO_2 and particulate for comparative analysis
- Linear rollback represents an adequate method for estimating the gross impacts on OX concentrations.
- CO air quality was not examined because of the need to utilize an alternative air quality model (e.g., APRAC-1A).

The primary focus of the study was to examine the impact of a "most favorable case" electrification scenario on air quality. Here "most favorable case" was defined in terms of locating all new power plants outside the study area (as is currently planned by the utilities) and providing for the rapid introduction of electrics and residential/commercial retrofitting inside the region. The justification behind this assumption

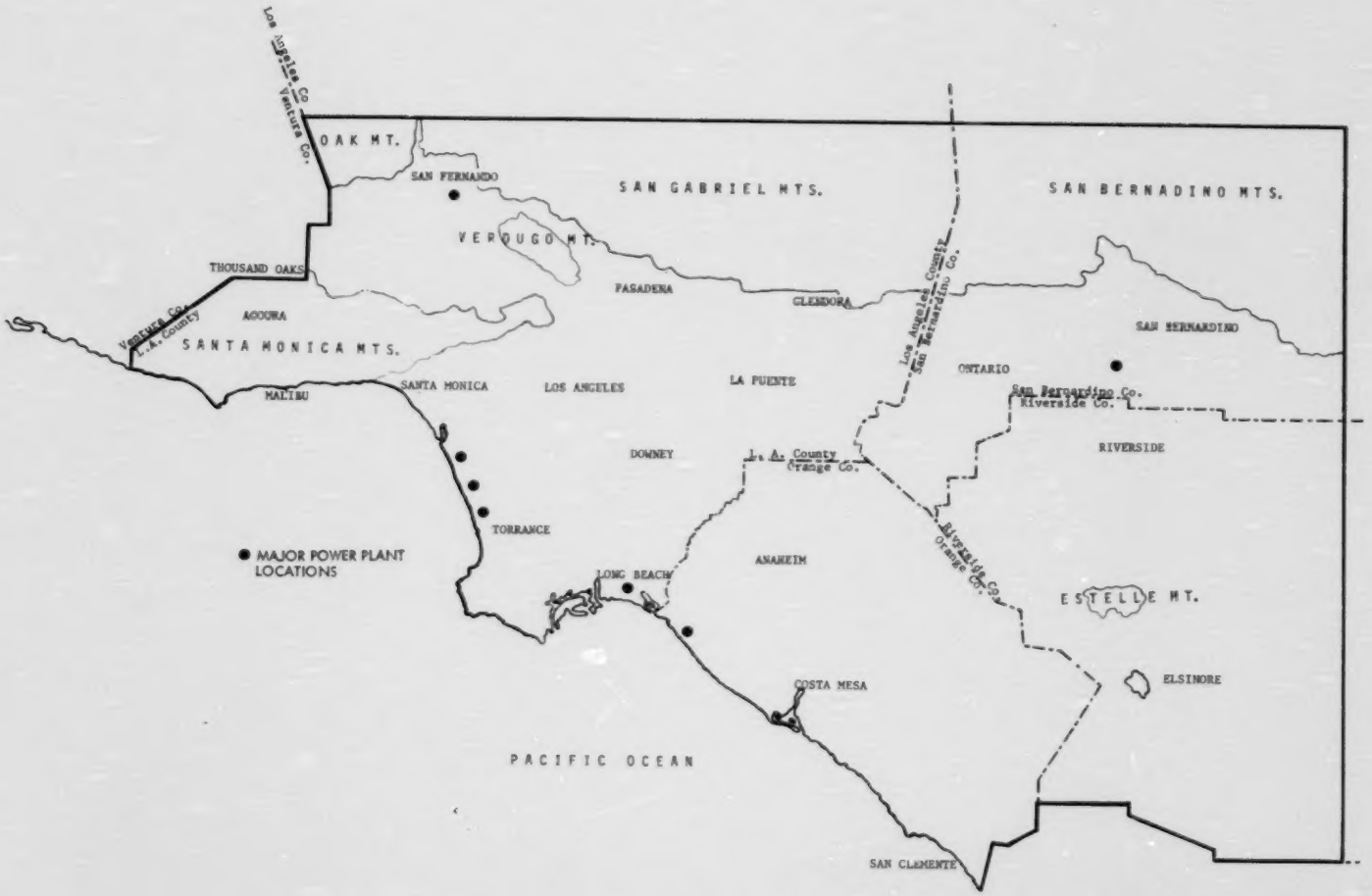


Figure 3. Los Angeles Study Region

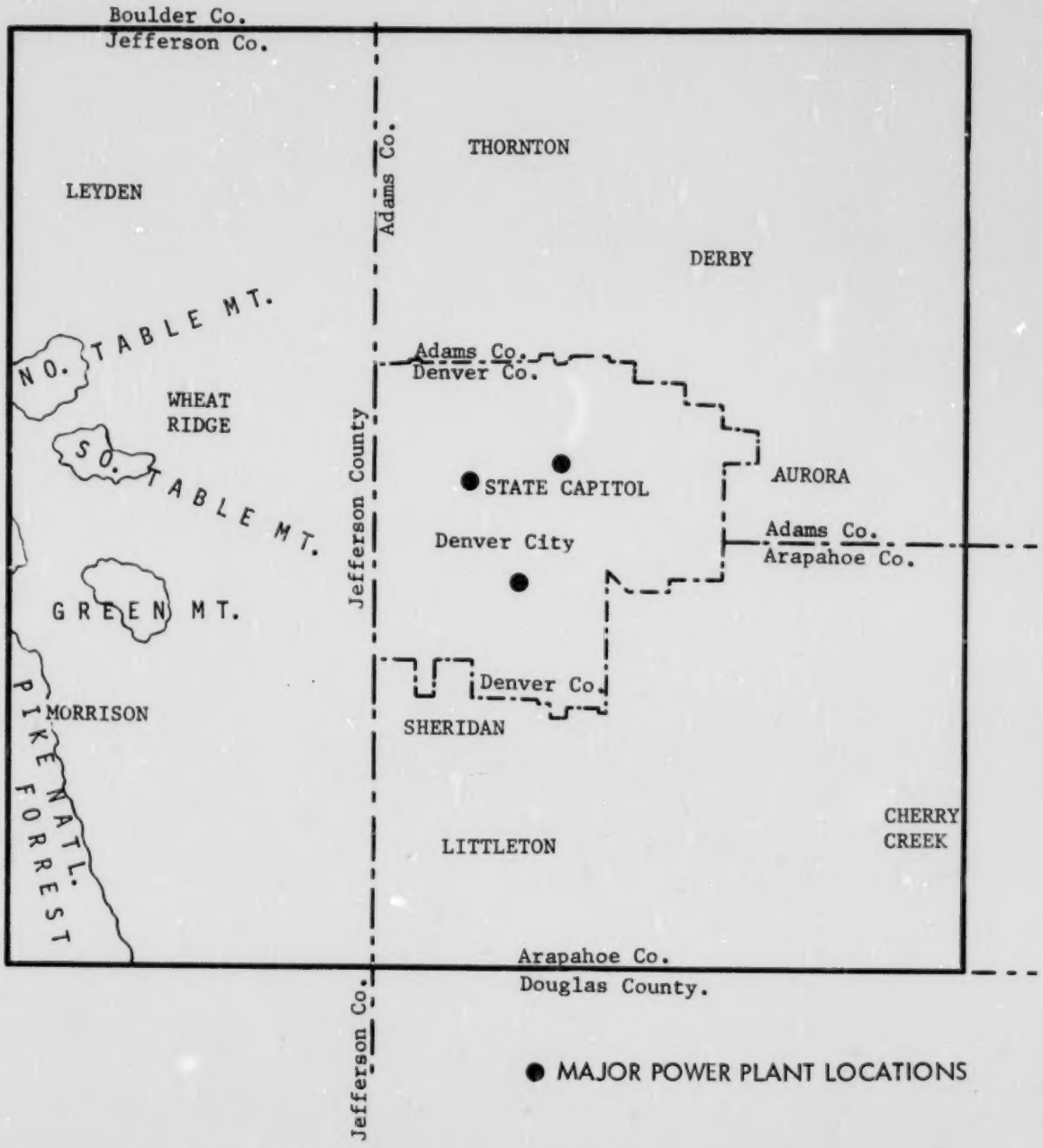


Figure 4. Denver Study Region

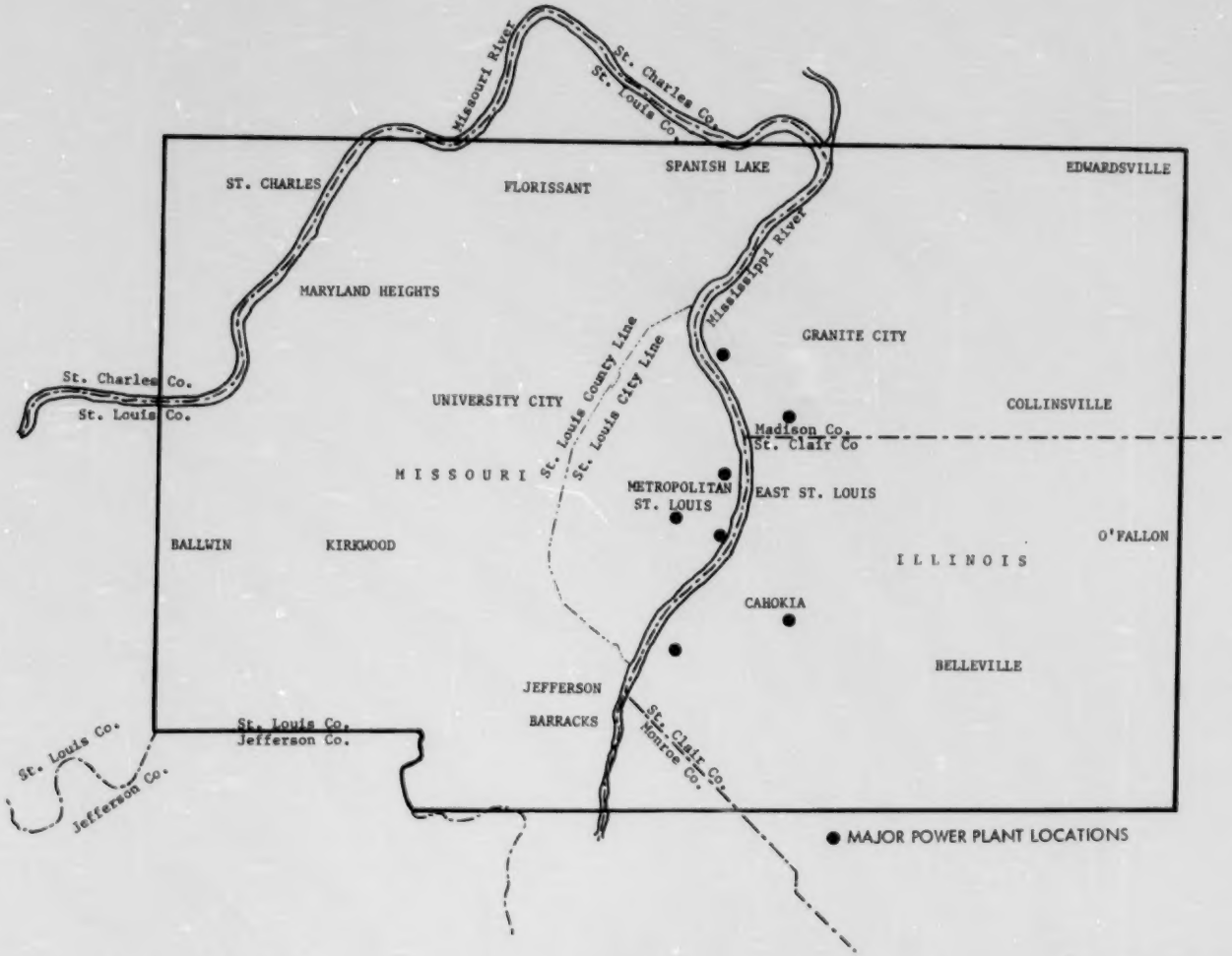


Figure 5. St. Louis Study Region

was that if this scenario did not have a favorable impact on air quality, then less extensive electrical energy end use and/or the location of additional power plants inside the region would clearly result in even less advantageous outcomes.

Another important limitation of this analysis involved the prediction of air quality. The theoretical and empirical limitations of both CDM and rollback are well documented [22], [30]. However, these models appear adequate for comparative analysis, which was the central purpose of this study. The actual forecasted air quality concentration over the 20-year period should be viewed as approximate. The essential use of these values is in cross-comparing the impact of alternative scenarios on air quality predictions.

Finally, it should be noted that the study requirements precluded a definitive literature review or the synthesis of new data. This is obviously an area requiring attention if additional analyses are to be performed.

SECTION IV
REGIONAL DATA BASE FOR 1975

A 1975 data base was established for each of the candidate regions. The data base consisted of energy use by sector, emissions by source and air quality for four pollutants. In addition to providing a benchmark for measuring the impact of alternative scenarios, the data base also was used to calibrate the air quality models. Calibration runs were made for contrasting actual versus predicted air quality levels.

The study boundaries for each region were developed to allow for the maximum utilization of existing emissions and energy use data. Actual census tract data were used to derive the required demographic characteristics for each region. A comparison of representative demographic data is presented in Table 2.

EMISSION CHARACTERISTICS

The major source of emissions data for each region was the National Emission's Data System (NEDS) [48] and region specific estimates developed from numerous studies ([2], [24], [25], [35], [40], [41]).

All the emissions data were updated to conform to the energy use characteristics of the region. The emissions data were developed in three categories:

- Stationary point sources
- Stationary area sources
- Mobile area sources

The stationary point sources include major industrial complexes and utilities. Stationary area sources include space and water heating, cooking, ships and railroads, agricultural, retail gasoline marketing, organic solvent usage and aircraft.

Stationary point sources for the Los Angeles study region were derived from a number of emission inventories ([24], [40], [48]) and then updated to be consistent with the fuel use data discussed below.

TABLE 2

REGIONAL DEMOGRAPHIC CHARACTERISTICS

	Current Population (Million)	Growth Potential (%)	Vehicle park (Million)	Area (Sq. Mi.)
Los Angeles	9.64	1.	5.5	4400.
Denver	1.23	3.	0.86	625
St. Louis	2.03	2.	1.0	780

Area source data include heavy duty diesel, ships and railroads, agricultural, domestic and space heating, retail gasoline marketing, and organic solvent usage. Total area emissions were obtained from [40] and distributed across the study area with the population distribution obtained from the Southern California Association of Governments [32]. Aircraft emissions were distributed to the grid squares occupied by the major airports in the region.

Stationary point sources for the Denver study region were derived from a number of emission inventories ([36], [39], [48]) and then updated to be consistent with the fuel use data discussed below. Area source data were derived primarily from [36] and updated with current fuel use data.

The primary sources of emissions data for St. Louis were [2], [25], and [41]. These data were available in grid format for stationary area sources and major point sources in the region.

Mobile area sources are derived from spatially distributed vehicle miles travelled (VMT) and emission factors based on the vehicle population mix (model year, light duty, heavy duty, motorcycles). Figure 6 highlights the relative contribution of mobile source emissions in each region. As indicated there are significant differences in the role of mobile sources particularly for NO_x, TSP and HC. The smaller NO_x percentage for Denver is directly relatable to the fact that automobiles generate lower NO_x emission levels at altitude.

Mobile source emissions for Los Angeles were estimated from traffic volume data supplied by the California Department of Transportation (CALTRANS). Employing the methodology outlined in [53], emission factors (grams/mile) were obtained and applied to the vehicle data. Vehicle population and VMT distributions by vehicle age were derived from [26].

In the case of Denver, traffic volume data were supplied by the Denver RTD. Figure 6 indicates that mobile source emissions constitute a lower percentage of total emissions than in Los Angeles. However, as a rapidly expanding region, mobile source emissions will produce a greater proportion of the total regional emissions in the future. Currently the Denver area level of per capita automobile ownership is among the highest in the country.

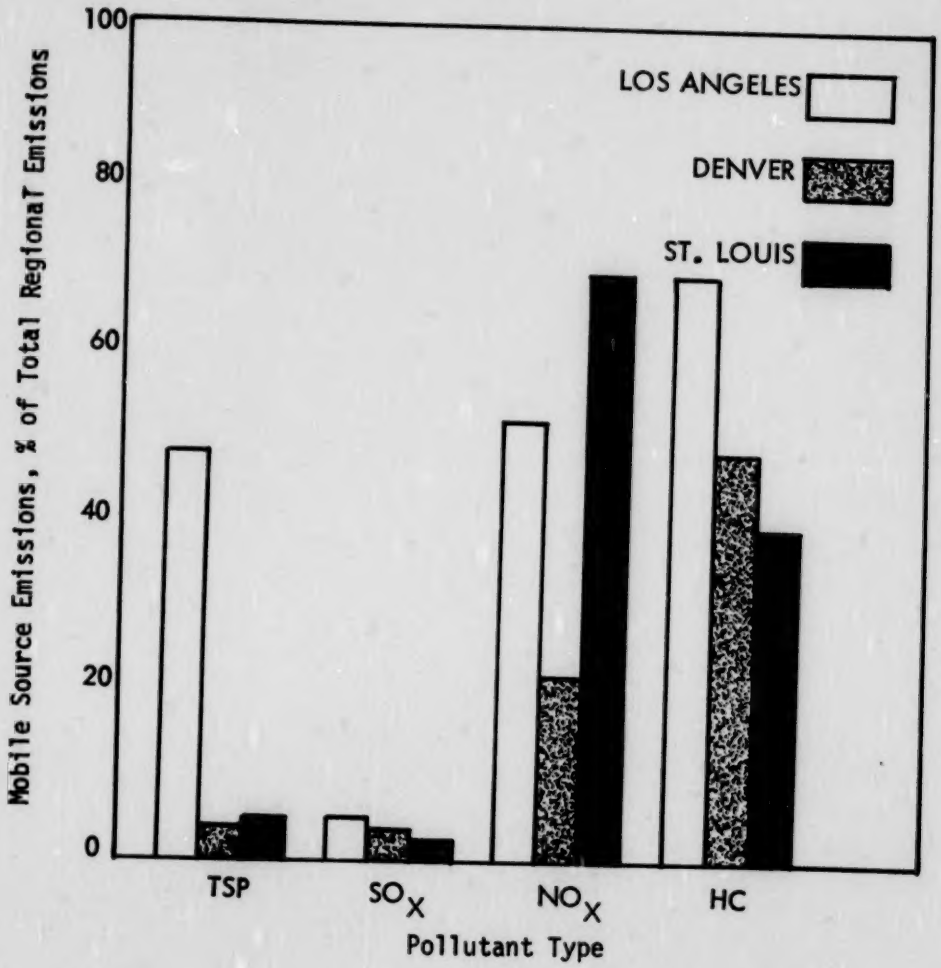


Figure 6. Relative Contribution of Mobile Source Emissions - 1975

Estimates of mobile source emissions for St. Louis were derived in a manner similar to that for Los Angeles and Denver. VMT data were obtained from the PEDCO Report [25].

Figures 7 and 8 show plots of VMT distribution for Los Angeles and Denver, respectively. An equivalent data format was not available for St. Louis.

ENERGY INVENTORY

The major source of energy use data was the public utilities ([6], [15], [16], [27], [28], [33], [37], [42]) in the study regions and detailed census data ([45], [46].

Additional energy use characteristics were obtained from national average data ([1], [7], [18], [20], [21], [50]) and specific regional data available from numerous studies.

The majority of the data management gathering effort involved data manipulation required to apportion the energy use data to the actual study regions. The energy use data were developed for four end-use sectors in this study:

- Residential/commercial
- Industrial
- Transportation
- Electric generation

It should be noted that the energy used by the electric utility sector is that quantity of fuel burned in each study region to generate electric power. The electric power generated within the region may or may not actually be used to meet the demand in the region since energy may be exported to other regions. The majority of electric energy used by the other three sectors may be imported. From a differential air quality impact point of view, one need not balance the electric energy generated with the electric energy consumed within a region.

Table 3 presents a comparison of electrical power supply and demand and energy end-use between regions. The supply and demand figures are given in terms of fuel consumption (there is an approximate 3 to 1

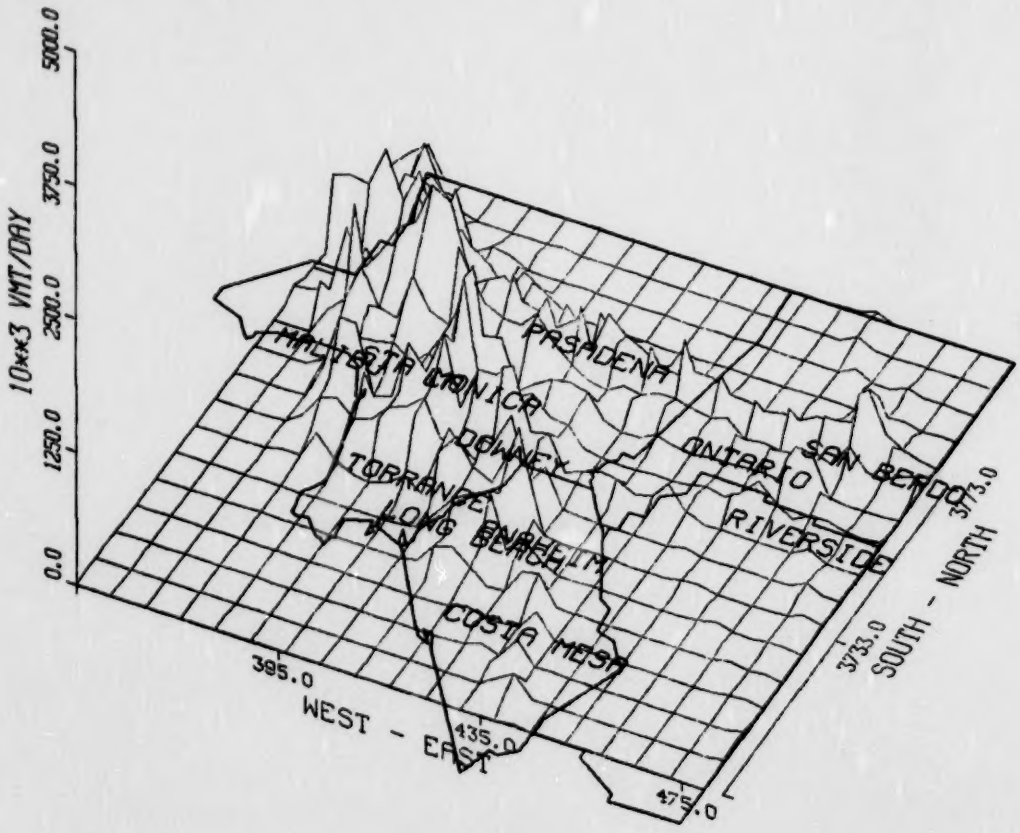


Figure 7

1975 VMT Distribution For Los Angeles

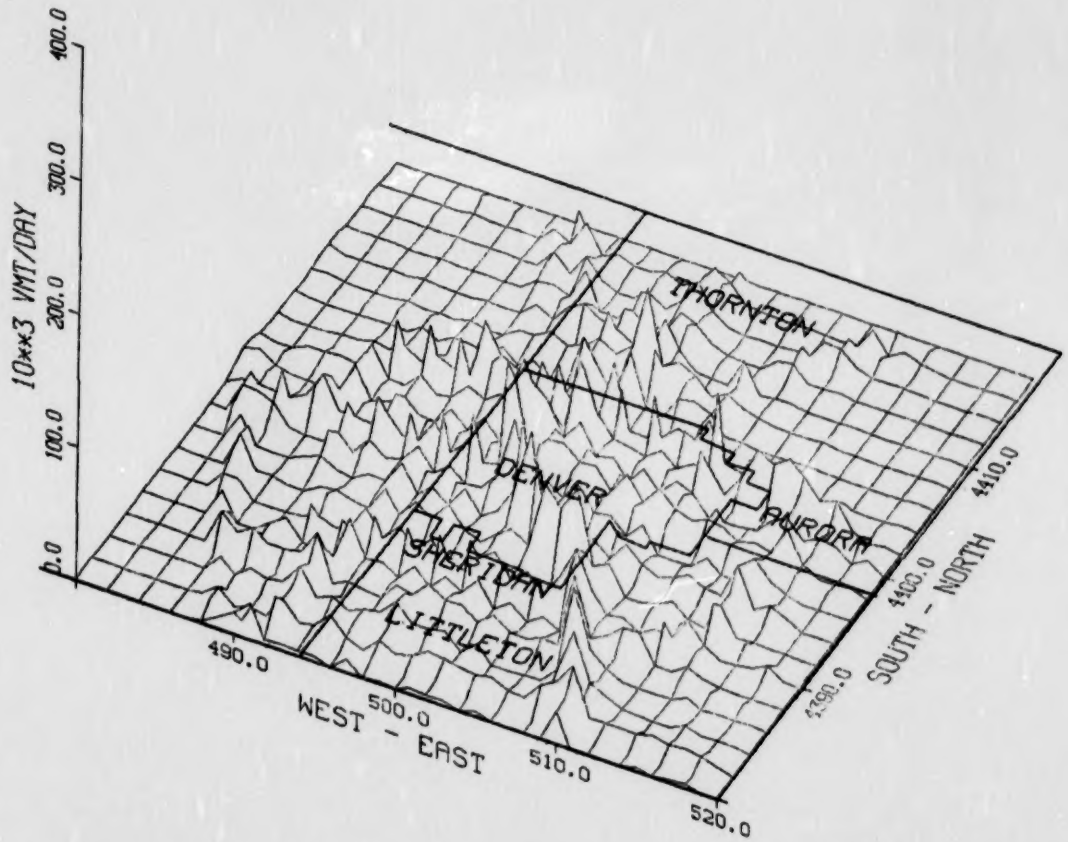


Figure 8

1975 VMT Distribution For Denver

TABLE 3

COMPARISON OF REGIONAL ENERGY CHARACTERISTICS FOR 1975

	ELECTRICAL POWER (10^{13} BTU)		END USE FUEL CONSUMPTION (%)			
	SUPPLY	DEMAND	COAL	OIL	N GAS	ELECTRICITY
LOS ANGELES	33	60	0	43	43	14
DENVER	8.9	5.7	1	37	52	10
ST. LOUIS	1.4	13.8	8	29	52	11

ratio between fuel burned and resultant electric power generated). One can see that Los Angeles and St. Louis are net importers of electric power while Denver generates approximately 50 percent more power than is required to meet local demand. The percentage estimates for energy end use consumption reveal major differences between regions, particularly for coal use.

Tables 4, 5, and 6 present a summary overview of current energy supply and demand for each region. The estimates are given in terms of both actual units and equivalent Btu units. Los Angeles consumes approximately 1.75 Quads per year, while Denver and St. Louis consume 0.29 and 0.41 quads per year, respectively.

Residential/Commercial

In Los Angeles 27 percent of the electrical energy is consumed for residential use, even though 85 percent of the customers are in this class. This is in contrast with the national average of 33 percent for residential use. This lower consumption is attributed to the milder climate in Los Angeles, size of dwelling unit, concentration of business and industry within the region, and the availability of alternate fuels at competitive prices. The distribution of residential electric use in Los Angeles in 1970 and projected for 2000 is shown in Table 7. Commercial consumption accounts for 30 percent of the electricity used in the Los Angeles area. The distribution of commercial loads in the study region for the 1973-1980 time period is shown in Table 8.

Approximately 75 percent of the energy consumed in the residential/commercial sector is from natural gas. Table 9 indicates the relative usage of natural gas and electricity in the residential sector.

In the Denver study region 27 percent of the electrical energy is for residential use, even though 88 percent of the customers are in this class. The commercial sector consumes nearly 40 percent of the electricity in the Denver study region.

Approximately 78 percent of the energy consumed in the residential/commercial sectors is supplied by natural gas. Table 10 shows the relative

TABLE 4

LOS ANGELES ENERGY USE DATA FOR 1975

STUDY AREA Los Angeles YEAR 1975

ENERGY SOURCE / ENERGY USE	RESIDENTIAL COMMERCIAL	TRANSPORTATION	INDUSTRY	ELECTRIC UTILITIES	TOTAL
Coal	----	----	5.800×10^3 TONS (1.624×10^{11} BTU)	----	5.800 x 103 TONS (1.624×10^{11} BTU)
Petroleum Residual	----	----	3.561×10^5 BBL (2.169×10^{12} BTU)	5.424×10^7 BBL (3.303×10^{14} BTU)	5.460×10^7 BBL (3.324×10^{14} BTU)
Distillate/ Diesel	1.110×10^4 BBL (6.294×10^{10} BTU)	1.128×10^7 BBL (6.396×10^{13} BTU)	8.354×10^5 BBL (4.737×10^{12} BTU)	4.800×10^4 BBL (2.722×10^{11} BTU)	1.217×10^7 BBL (6.903×10^{13} BTU)
Gasoline	----	1.021×10^8 BBL (5.360×10^{14} BTU)	----	----	1.021×10^8 BBL (5.360×10^{14} BTU)
Natural Gas	3.803×10^8 MCF (3.803×10^{14} BTU)	----	2.250×10^8 MCF (2.250×10^{14} BTU)	NONE AFTER 9/75	6.053×10^8 MCF (6.053×10^{14} BTU)
Electricity	3.986×10^7 MWH (1.360×10^{14} BTU)	----	1.864×10^7 MWH (6.360×10^{13} BTU)	----	5.850×10^7 MWH (1.996×10^{14} BTU)
Total BTU	5.164×10^{14}	6.000×10^{14}	2.957×10^{14}	3.306×10^{14}	17.427×10^{14}

TABLE 5

DENVER ENERGY USE DATA FOR 1975

STUDY AREA Denver YEAR 1975

ENERGY SOURCE / ENERGY USE	RESIDENTIAL COMMERCIAL	TRANSPORTATION	INDUSTRY	ELECTRIC UTILITIES	TOTAL
Coal	3.326×10^6 TONS (9.313×10^{11} BTU)	----	4.556×10^4 TONS (1.276×10^{12} TONS)	1.959×10^6 TONS (5.485×10^{13} BTU)	2.038×10^6 TONS (5.706×10^{13} BTU)
Petroleum Residual	2.309×10^5 BBL (1.406×10^{12} BTU)	----	1.368×10^5 BBL (8.311×10^{11} BTU)	3.30×10^5 BBL (2.010×10^{12} BTU)	6.977×10^6 (4.249×10^{12} BTU)
Distillate/ Diesel	7.994×10^5 BBL (4.533×10^{12} BTU)	1.084×10^6 BBL (6.146×10^{12} BTU)	4.678×10^5 BBL (2.652×10^{12} BTU)	----	2.351×10^6 BBL (1.333×10^{13} BTU)
Gasoline	----	1.103×10^7 BBL (5.791×10^{13} BTU)	----	----	1.103×10^7 BBL (5.791×10^{13} BTU)
Natural Gas	7.375×10^7 MCF (7.375×10^{13} BTU)	----	3.065×10^7 MCF (3.065×10^{13} BTU)	3.19×10^7 MCF (3.19×10^{13} BTU)	1.363×10^8 MCF (1.363×10^{14} BTU)
Electricity	4.198×10^6 MWH (1.432×10^{13} BTU)	----	1.473×10^6 MWH (5.026×10^{12} BTU)	----	5.671×10^6 MWH (1.935×10^{13} BTU)
Total BTU	9.494×10^{13}	6.405×10^{13}	4.044×10^{13}	8.876×10^{13}	2.882×10^{14}

TABLE 6

ST. LOUIS ENERGY USE DATA FOR 1975

STUDY AREA ST. LOUIS YEAR 1975

ENERGY SOURCE \ ENERGY USE	RESIDENTIAL COMMERCIAL	TRANSPORTATION	INDUSTRY	ELECTRIC UTILITIES	TOTAL
Coal	7.0×10^4 TONS (1.96×10^{12} BTU)	----	6.847×10^5 TONS (1.917×10^{13} BTU)	4.119×10^5 TONS (1.153×10^{13} BTU)	1.219×10^7 TONS (3.266×10^{13} BTU)
Petroleum Residual	2.011×10^6 BBL (1.225×10^{13} BTU)	----	2.207×10^5 BBL (1.344×10^{12} BTU)	2.052×10^4 BBL (1.250×10^{11} BTU)	2.252×10^6 BBL (1.372×10^{13} BTU)
Distillate/ Diesel	2.667×10^4 BBL (1.512×10^{11} BTU)	1.912×10^6 BBL (1.084×10^{13} BTU)	4.488×10^5 BBL (2.545×10^{12} BTU)	3.569×10^5 BBL (2.024×10^{12} BTU)	2.744×10^6 BBL (1.556×10^{13} BTU)
Gasoline	----	1.730×10^7 BBL (9.083×10^{13} BTU)	----	----	1.730×10^7 BBL (9.083×10^{13} BTU)
Natural Gas and Propane	1.895×10^8 MCF (1.895×10^{14} BTU)	----	2.271×10^7 MCF (2.271×10^{13} BTU)	----	2.122×10^7 MCF (2.122×10^{14} BTU)
Electricity	6.812×10^6 MWH (2.324×10^{13} BTU)	----	6.687×10^6 MWH (8.282×10^{13} BTU)	----	1.350×10^7 MWH (4.606×10^{13} BTU)
TOTAL BTU	$\times 10^{14}$	1.017×10^{14}	6.859×10^{13}	1.368×10^{13}	4.111×10^{14}

TABLE 7

DISTRIBUTION OF RESIDENTIAL ELECTRIC USE
IN LOS ANGELES

1970 - 2000

	Actual Percent Residential Use 1970	Projected Percent Residential Use 2000
Lights and Miscellaneous	14.02	12
Refrigerator	24.40	19
Freezer	4.56	2
Television	9.96	12
Wringer Washer	0.05	0
Automatic Washer	1.04	1
Electric Range	3.14	5
Electric Dryer	2.70	2
Electric Room Air Conditioning	7.75	6
Electric Central Air Conditioning	7.52	14
Electric Water Heating	5.13	3
Electric Space Heating	12.33	16
Pool Pumps	3.69	5
Dishwasher	1.82	1
Household Appliances	1.83	1
Other	0.06	1

TABLE 8

ANTICIPATED DISTRIBUTION OF NEW COMMERCIAL LOADS
IN LOS ANGELES
1973 - 1980

Use	Percent
Office Buildings and Large Commercial Projects; e.g., Convention Center, Broadway Plaza, Northridge Fashion Square, etc.	26
Hospitals and Medical Buildings	22
Government Buildings and Public Service Facilities	16
Food and Other Retail Stores	14
Schools and Churches	7
Financial Institutions	7
Hotels and Motels	4
Miscellaneous	4

TABLE 9

COMPARISON OF FUEL USES

IN RESIDENTIAL SECTOR, LOS ANGELES - 1975

	% of Total Housing Units	No. Housing Units	Total Btu/Yr ($\times 10^{13}$)	Btu/Dwel-Yr ($\times 10^{7}$)	Total %
Space Heating					62
Gas	90.1	2756000	17.79	6.456	
Electric	7.7	235000	.587	7.489*	
Other					
Water Heating					26
Gas	92.4	2826000	7.63	2.7	
Electric	5.8	179000	.2442	4.092	
Cooking					9
Gas	82.7	2529000	2.66	1.05	
Electric	16.	488000	.1495	.918	
Dryer					3
Gas	21.	641000	.5768	.90	
Electric	14.5	443000	.1285	.87	

* Equivalent fuel at source assuming 30% efficiency.

TABLE 10

COMPARISON OF FUEL USES
IN RESIDENTIAL SECTOR, DENVER - 1975

	% of Total Housing Units	No. Housing Units	Total Btu/Yr ($\times 10^{12}$)	Btu/Dwel-Yr ($\times 10^{7}$)
Space Heating				
Gas	92	328000	41.03	12.5
Electric	4	15000	2.2	14.5
Water Heating				
Gas	89.5	320000	8.63	2.7
Electric	7	26000	1. 6	4.8
Cooking				
Gas	44	158000	1.657	1.05
Electric	54	193000	2.31	1.2
Dryer				
Gas	7	28000	.254	.9
Electric	36	130000	1.86	1.43

usage of natural gas and electricity in the residential sector. The residential sector consumes nearly 50 percent of the natural gas in the region. The use of coal, fuel oil and distillate for the residential/ commercial sector were determined from [36] and [45].

In the St. Louis study region approximately 50 percent of the electric energy and almost 90 percent of natural gas is used by the residential/ commercial sector. Table 11 indicates the relative usage of natural gas, electricity and other fuels in the residential sector.

Industrial

Less than 30 percent of the electricity used in the Los Angeles region is consumed by the industrial sector [15]. The distribution of industrial electricity use is shown in Tables 12 and 13. Natural gas accounts for more than 75 percent of the fuel used in the industrial sector in the Los Angeles study region according to [46]. Petroleum and coal use in the study region also were obtained from [46].

In Denver, the industrial sector consumes less than 25 percent of the total electrical bill. Furthermore, less than 25 percent of the natural gas consumed in the region is by the industrial sector, although this fuel accounts for 75 percent of the industrial energy use. Petroleum and coal use estimates were derived from [46].

Coal, natural gas and electricity are used approximately equally in supplying the industrial sector in St. Louis.

Electric Generation

Current shortages of natural gas in Los Angeles will eliminate any supplies to electric utilities after September, 1975. As reported by the SCEC and DWP, the only fuels burned in the study region are residual and distillate oil. Because of the nature of this study, i.e., impact on air quality, only fossil fuels burned within the study region are included in the fuel usage data. Nuclear power plants, although within the area are not considered from an air quality standpoint but are considered in meeting energy demand. It should also be noted that Los Angeles is a net

TABLE 11

COMPARISON OF FUEL USES

IN RESIDENTIAL SECTOR, ST. LOUIS - 1975

	% of Total Housing Units	No. Housing Units	Total Btu/Yr ($\times 10^7$)	Btu/Dwel-Yr ($\times 10^7$)
Space Heating				
Gas	77	490000	61.48	12.5
Fuel Oil	12	79000	10.86	13.8
LP Gas	6	38000	4.700	12.5
Electric	2.8	18000	2.589	14.5
Coal	1.9	12000	2.589	14.5
Water Heating				
Gas	77.8	500000	13.5	2.7
Electric	13.	86000	4.139	4.82
LP Gas	6.	37000	.998	2.7
Cooking				
Gas	63.2	406000	4.467	1.1
Electric	29.	187000	2.30	1.23
LP Gas	7.	45000	.493	1.1
Dryer				
Gas	21.	136000	1.22	.9
Electric	24.	153000	2.18	1.43

TABLE 12

DISTRIBUTION OF INDUSTRIAL LOAD

CONNECTED IN LOS ANGELES - 1970 TO 1972

Type of Load	Connected Load, kw	Percent of Total
Motors	212,171	65
Industrial Lighting	39,512	12
Process Heating	35,785	11
Internal Climate	29,012	9
Resistance Welders	6,868	2
Miscellaneous	3,000	1

TABLE 13

INDUSTRIAL USES OF ELECTRIC ENERGY IN LOS ANGELES

Industry	Percent
Petroleum	21.4
Aerospace	15.8
Chemicals	7.9
Stone, Clay, Glass	7.4
Food Processing	2.8
Paper Printing	2.8
Rubber	2.8
Metal Fabrication	2.3
Other	36.8

importer of electrical energy, further increasing the discrepancy between electrical energy consumed and electrical energy generated.

Fossil-fueled power plants generated nearly 97 percent of the electric energy in the Denver region. A nuclear power plant is presently under construction which will provide about 16 percent of total electric generation in 1978. Of the thermal production, approximately 50 percent is produced with coal and the remainder with residual petroleum and natural gas.

Nearly 85 percent of the fuel used for the generation of electric energy in the St. Louis area is coal. Distillate and diesel provide most of the remaining fuel sources for electric generation.

Transportation

VMT constitutes the singularly most important component in estimating the impact of mobile sources on air quality. Estimates of fuel consumption were derived primarily for reporting purposes. The quantity of gasoline and diesel fuel consumed were computed as a weighted average of fuel economy and fraction of VMT assigned to each vehicle type (e.g., light duty, heavy duty, diesel).

SECTION V

BASELINE PROJECTIONS OF REGIONAL ENERGY CONSUMPTION

This section contains baseline projections for the three regions in 1980, 1985, 1990 and 1995. Energy use is the principal factor influencing emission levels.

ENERGY USE PROJECTIONS

A number of regional energy consumption projections were surveyed for possible use in this study. For some energy forms, e.g., electricity, there are a number of alternative projections for a given region; for others, e.g., coal consumption, there are a paucity of forecasts. Some of the variations in projections are due to differences in the methodology employed and the assumptions made, while others are due to conceptual differences in the quantity being forcasted.

For instance some of the energy projections are purported to be estimates of demand, that is, the amount customers would be willing to purchase at a fixed set of prices, given income, population and other relevant factors. Other projections are intended for the actual amount consumed. When the price of the fuels is not at a level that equates demand with supply, the two concepts differ. This difference is illustrated in Figure 9.

At price P* the market is in equilibrium; the quantity demanded equals the quantity supplied Q*. At a price P_1 lower than P* the effective amount consumed is constrained to the quantity supplied Q_1 while purchaser would like to consume Q^D. Such a situation is presumably the case in many natural gas markets where the current price is lower than the equilibrium amount causing a "shortage" at current prices. Similarly, at a price P_2 higher than equilibrium, the quantity consumed is Q_2, the amount demanded, while suppliers would like to sell quantity Q^S.

The actual quantity consumed, if it is different from the quantity demanded, is the appropriate concept for this study, since the actual amount used gives rise to emissions.

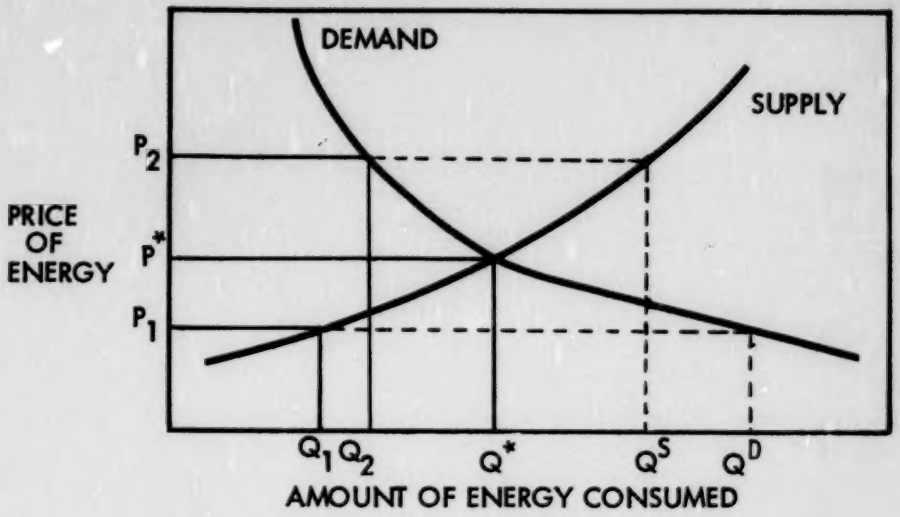


Figure 9. Difference Between Quantity Demanded and Quantity Consumed for a Market Out of Equilibrium

AVAILABLE PROJECTIONS

An extensive literature search and survey of local organizations revealed there were no projections of energy consumption for each of the study regions. Instead, for some electricity and gas utilities there were projections for their service areas while for other fuels, primarily the fossil fuels, region-wide projections were available. It was assumed that energy consumption growth rates in projections for broad areas containing the study regions were valid for the smaller entity.

Selection of an appropriate projection technique was based upon a combination of the following criteria: (1) a sound theoretical model for the quantities forecast in terms of selected economic and social factors; (2) consideration of relevant local factors; and (3) consistency with national energy use trends.

The projections are presented in the form of 5-year growth factors over the 20-year period (1975-1995) instead of absolute amounts of energy consumption. These growth factors are applied to the base year consumption estimates. This concept allows alternative projections to be compared without having to apportion the actual projection on a geographical basis as was done for the base year. The latter process would have required applying ratios of future population and income for the overall region and subregion and hence added other highly uncertain factors to the projections.

The most sophisticated methodology was employed by the FEA. It utilized an econometric model of demand for a set of interdependent fuels based upon prices, income, and population within each region. This approach permitted interfuel substitution over time as the relative prices of fuels changed. Unfortunately, the forecasts were only made for two future years, 1977 and 1985, and pertain to an entire census region. Each estimated fuel equation is based upon a combination of cross-section (individual state fuel consumption) and time series data.

The Stanford Research Institute (SRI) [34] energy projections are for all of Southern California Edison Company, Los Angeles Department of Water and Power, and San Diego Electric Company. It is primarily a composite of utility forecasts in the electric sector. For other fuel projections it is based upon past trends in California and was prepared in 1973 before the general price increases in electricity rates. As such, its forecasts are generally considerably higher than the other sources.

Projections for Petroleum Administration Districts (PADS) were prepared by the University of Illinois [29] and are composed of pre-oil embargo price rise projections made by the National Petroleum Council, Federal Power Commission and National Economic Research Associates. These estimates were primarily based upon an analysis of previous trends and assumed no variation in relative fuel prices.

Within the Los Angeles region an econometric forecast of electric power consumption by user class was prepared by the Southern California Edison Company, [53]. Other electric utilities in Los Angeles, Denver and St. Louis [15], [28], [42] areas provided only judgmental forecasts based upon analysis of past trends as well as future planned additions.

The only published projections of natural gas consumption for the Los Angeles region were prepared by the Southern California Gas Company [9] in 1974 for the Public Utilities Commission use. They assumed reduced net supplies with no new sources of supply and hence consumption was constrained to be equal to the dwindling supplies. Since that report, this utility has entered into agreement for Alaskan natural gas. Consequently, their projections were not employed. No other plausible forecasts were available from local gas companies in the other regions. The procedure used in developing estimates of future gas consumption is discussed below.

Forecasts of future vehicle miles traveled were available from local transportation agencies and served as the basis for projecting gasoline and diesel fuel in the transportation sector when combined with estimates of average fuel consumption.

PROJECTIONS UTILIZED

The following electric utility projections were selected for use in the analysis: those of SCE in Los Angeles, Union Electric in St. Louis, and Public Service Company of Colorado in Denver (for residential/commercial only). These forecasts are based upon regional conditions and, in the case of Southern California Edison, have utilized formal statistical techniques and accounted for economic factors. Furthermore, those forecasts were available over the entire time horizon, at least for Los Angeles and Denver. Estimates of electrical consumption in the industrial sector were extrapolated from the EPA projected growth rate in industrial electricity.

Natural gas consumption in the industrial sector was based upon the FEA projections because this sector has shown considerable response to price. The lack of any systematic projections by local gas companies precluded their use. For the residential/commercial sector, in Los Angeles the SRI projections did not account for increased prices and it was felt that the FEA forecasts which show an absolute decrease in consumption for the entire region were unrealistic. Similarly, declining projections of R/C consumption in Denver and St. Louis also was deemed inappropriate because the regions are growing and the margins for reduced usage for cooking and space heating are limited. Consequently, a conservative forecast

based upon population projections for these regions was employed as the basis for the growth estimates. An implication of this approach is that the amount of electrical power generation that must replace a natural gas demand will increase. Hence, this establishes an upper bound on the corresponding emissions that can be expected. If these emissions from increased electrification do not appreciably affect air quality, one may conclude, a fortior that lower demand will have even less impact.

Projections for coal in the industrial sector and residual fuel and distillate oil in the residential/commercial and industrial sectors were based upon FEA methodology with estimates beyond 1985 extrapolated to reflect lessened growth. The alternative PAD forecasts were not based upon a plausible theoretical or statistical methodology and, therefore, were not utilized. It was assumed that residential/commercial coal use would remain constant over the forecasting period.

Electric utility fuel use was based upon the electric utilities' projected plans for new additions of generating capacity, both within and outside the study area. These estimates included the type of plants planned in terms of their fuel source and the mix of baseload and peaking plants within the area. In the Los Angeles region, there are no planned additions to baseload plants.

In Denver a nuclear plant will add about 16 percent to the total capacity of the system in the 1975-1980 time interval. Consequently, 16 percent of the projected 32 percent increase in total output was assigned to this plant and the remainder of the increase to existing plants within the study area. Therefore, the fuel consumption of plants within the area, which are all coal fired, was increased proportionally. No additional plants are planned in the Denver area for the rest of the planning period and thus the existing plants' fuel consumption was increased at the same rate of growth as total projected electrical consumption.

In the St. Louis area, the planned nuclear plant, projected to go on line between 1981 and 1983, will be able to accomodate the entire increase in demand during the 1980-1985 interval since its addition equalled about the projected increases in demand during this period. In the other periods the coal-fired plants were assumed to increase their fuel use proportional to total increases in demand.

Tables 14, 15 and 16 give the estimated 5-year energy growth factors for Los Angeles, Denver and St. Louis, respectively.

TABLE 14

FIVE-YEAR GROWTH FACTORS FOR FUEL USE IN LOS ANGELES

BASELINE CASE

		1975-80	1980-85	1985-90	1990-95
RESIDENTIAL/COMMERCIAL					
	DISTILLATE	.92881	1.00386	1.00386	1.00386
	NATURAL GAS	1.056	1.05127	1.05127	1.05127
	ELECTRICITY	1.2635	1.34455	1.30076	1.26118
TRANSPORTATION					
	DIESEL	1.06716	1.13262	1.10500	1.10500
	GASOLINE	.93000	.88	.85	.82
INDUSTRIAL					
	COAL	1.	1.	1.	1.
	RESIDUAL	1.06609	1.14889	1.13315	1.13315
	DISTILLATE	1.06609	1.14889	1.13315	1.13315
	NATURAL GAS	1.11438	1.08215	1.07788	1.0788
	ELECTRICITY	1.13695	1.22840	1.20500	1.18193
ELECTRIC UTILITIES*					
	RESIDUAL	1.	1.	1.	1.
	DISTILLATE	1.	1.	1.	1.

* Demand to be met outside region

TABLE 15

FIVE-YEAR GROWTH FACTORS FOR FUEL USE IN DENVER

BASELINE CASE

		1975-80	1980-85	1985-90	1990-95
RESIDENTIAL/COMMERCIAL					
	COAL	1.	1.	1.	1.
	RESIDUAL	1.15263	1.20274	1.19125	1.19125
	DISTILLATE	.68052	.82045	.82045	.82045
	NATURAL GAS	1.05127	1.05127	1.05127	1.05127
	ELECTRICITY	1.35859	1.34521	1.37733	1.37809
TRANSPORTATION					
	DIESEL	1.06892	1.13366	1.10517	1.10517
	GASOLINE	1.022	1.039	1.052	1.063
INDUSTRIAL					
	COAL	1.21149	1.13094	1.13094	1.13094
	RESIDUAL	1.15263	1.20274	1.19125	1.19125
	DISTILLATE	1.15263	1.20274	1.19125	1.19125
	NATURAL GAS	1.06359	1.05506	1.05127	1.05127
	ELECTRICITY	1.21410	1.17117	1.17117	1.17117
ELECTRIC UTILITIES					
	COAL	1.1700	1.3037	1.3333	1.3394
	RESIDUAL	1.	1.	1.	1.
	NATURAL GAS	1.	1.	1.	1.

TABLE 16

FIVE-YEAR GROWTH FACTORS FOR FUEL USE IN ST. LOUIS

BASELINE CASE

		1975-80	1980-85	1985-90	1990-95
RESIDENTIAL/COMMERCIAL					
	COAL	1.	1.	1.	1.
	RESIDUAL	1.22667	1.20532	1.19125	1.19125
	DISTILLATE	1.	1.03915	1.03915	1.03915
	NATURAL GAS	1.0356	1.0359	1.0356	1.0356
	ELECTRICITY	1.33196	1.31318	1.28402	1.28402
TRANSPORTATION					
	DIESEL	1.05622	1.11611	1.10517	1.10517
	GASOLINE	.99	.996	1.014	1.043
INDUSTRIAL					
	COAL	1.50133	1.39368	1.34986	1.34986
	RESIDUAL	1.22667	1.20532	1.19125	1.19125
	DISTILLATE	1.22667	1.20532	1.19125	1.19125
	NATURAL GAS	.99795	.82218	.86070	.86070
	ELECTRICITY	1.25820	1.22752	1.19125	1.19125
ELECTRIC UTILITIES					
	COAL	1.29570	1.	1.24095	1.24234
	RESIDUAL	1.	1.	1.	1.
	DISTILLATE	1.	1.	1.	1.

SECTION VI

ELECTRIC SUBSTITUTION

The primary objective of this project was to analyze the impact of intensive use of electricity on air quality. Several alternative scenarios were examined relative to their impact on air quality. The parameters associated with electrification are (1) the energy source and sector being converted to electricity and (2) the degree of electrification introduced. The following sectors and energy uses were identified for possible electrification:

- Residential/Commercial
  - Space heating
  - Water heating
  - Cooking
  - Clothes drying
- Transportation
  - Light duty vehicles
- Industrial
  - Processes

Investigation into the industrial sector revealed that the development of a reasonable industrial electrification scenario would require analysis beyond the scope of the current effort. Current estimates indicated that only approximately 10-15 percent of industrial energy use could be supplied by electrical power. Thus, only the residential/commercial and transportation electrification scenarios were considered.

The degree of electrification is a function of the technological and implementation constraints assumed. The approach taken in this study was to assume that the degree of electrification is primarily a function of the technological aspects of the substitution. Although this electrification scenario may imply unrealistic implementation procedures, an upper limit will be established on the impact on air quality. If these

high rates of technical substitution do not have an appreciable impact on air quality levels, then lower rates of introduction should have even less effect.

The question as to where the additional electric energy will be generated will also have a significant impact on the results of this study. A review of current utility plans indicated that no additional fossil fuel power plants will be sited within the study regions. It should be noted, however, that for Denver and St. Louis increases in generating capacity are anticipated to occur at existing plants. The increased electrical output was proportioned to the ratio of baseline capacity of the system serving the region. In addition, capacity increases within the region were allocated according to relative plant capacities.

RESIDENTIAL/COMMERCIAL ELECTRIFICATION

Electrification in the residential/commercial sector consists of retrofit and/or introduction of electric space heating, water heating, cooking and clothes drying. Figure 10 shows total forecasted electrical growth for the two scenarios.

Electrification in this sector reverses the relative increase in total electricity use between Denver and St. Louis. In the baseline, Denver growth is higher than St. Louis due, primarily, to the higher increases in population. However, with intensive electrification, the growth in St. Louis electrical demand surpasses Denver because of the greater present penetration of natural gas in the St. Louis region.

Residential/Commercial Space Heating

The largest single energy-consuming function in the home is space heating. In an average all-electric home in a moderate climate, space heating uses over half the energy delivered to the home; in gas- or oil-heated homes, the fraction is larger because thermal insulation is not as prevalent where these fuels are used.

The electrification scenario consists of the conversion (retrofit) of all existing non-electric space heating to electric over the 20-year study period. All new housing units over this period will be heated electrically. It

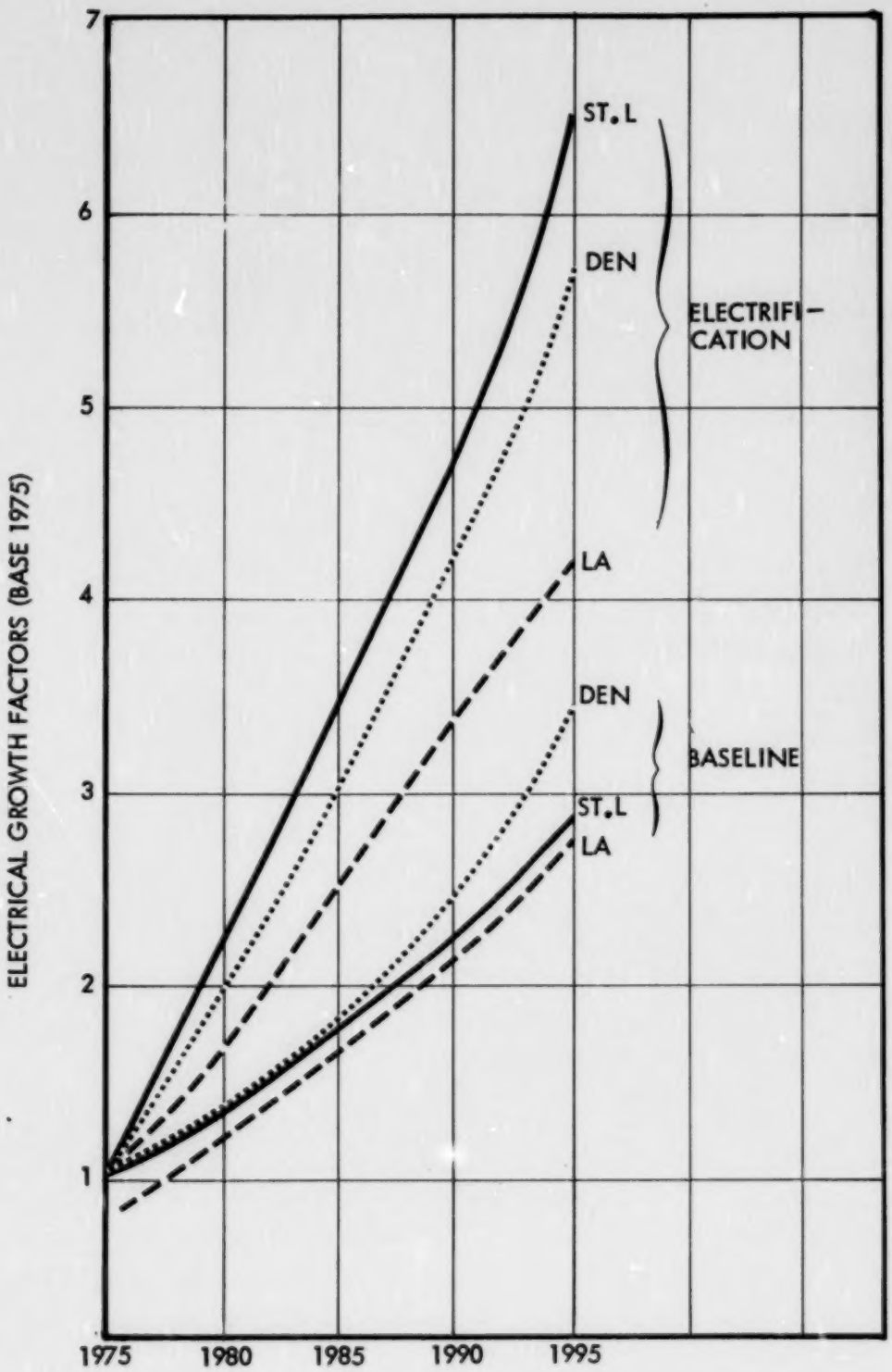


Figure 10. Forecasted Electrical Growth in Residential/Commercial Sector

should be noted that electric heating is a less efficient use of primary energy than is direct combustion heating. The average efficiency for electric power plants in the United States is about 33 percent, and the efficiency of transmitting and distributing the power to the customer is about 90 percent. The end-use efficiency of electrical heating is close to 100 percent, an indication that the overall efficiency is approxiamtely 30 percent. Thus, for every unit of heat delivered to the home, 3.3 units of heat must be extracted from the fuel at the power plant. Conversely, the end-use efficiency of gas- or oil-burning home heating systems is about 60 percent (claimed values range from 40 to 80 percent [1], [21]), meaning that 1.7 units of heat must be extracted from the fuel for each unit delivered to the living area of the home. Therefore, the electrically heated home requires about twice as much fuel per unit of heat as the gas- or oil-heated home, assuming equivalent insulation. Table 17 presents the baseline and electrification energy requirements for space heating for the 20-year study period by region.

Water Heating

Water heating accounts for 8 percent of all residential energy use. Most single family homes in the three study regions have natural gas water heaters as indicated in Table 18.

Electricity is the most fuel intensive energy source, and the amount of energy needed to run electric water heaters has been increasing. In 1959, the average electric water heater used about 43 million Btu's annually. By 1969, its energy use had increased to 46 million Btu's, but a new, more energy intensive model was on the market as well - a quick-recovery electric water heater that uses 52 million Btu's annually. Energy used in natural gas water heaters has also increased, from an average of 24 million Btu's in 1960 to 32 million Btu's in 1971. Hot water is used for washing dishes, clothes and people. The amount used varies with the number of people in the household and the use of appliances that consume large amounts of hot water, such as automatic dishwashers and clothes washers. The average annual energy requirements per dwelling used in this study was derived from [10]. The electrification scenario assumes conversion to electric water heating over the 20-year study period and

TABLE 17

SPACE HEATING SCENARIOS
FOR RESIDENTIAL/COMMERCIAL SECTOR

Energy Consumption - 10^{13} Btu

	1975		1980		1985		1990		1995	
Los Angeles	B	E	B	E	B	E	B	E	B	E
Gas	17.79	17.79	18.78	13.34	19.75	8.89	20.76	4.45	21.83	0.
Electric	.59	.59	.74	11.6	.99	22.71	1.30	33.92	1.64	45.29
Denver										
Gas	4.10	4.10	4.31	3.08	4.53	2.05	4.77	1.03	5.01	0.
Electric	.22	.22	.29	2.40	.40	4.61	.55	6.89	.76	9.24
St. Louis										
Gas	6.15	6.15	6.36	4.61	6.59	3.07	6.83	1.54	7.07	0.
Electric	.26	.26	.35	4.62	.45	9.02	.58	13.45	.75	19.33
Fuel Oil	1.09	1.09	1.09	.83	1.13	.54	1.17	.28	1.22	0.
LPG	.47	.47	.58	.35	.69	.24	.82	.12	.98	0.
Coal	.19	.19	.19	.14	.19	.09	.17	.05	.19	0.

B = Baseline E = Electrification

TABLE 18

WATER HEATING SCENARIOS
FOR RESIDENTIAL/COMMERCIAL SECTOR

Energy Consumption - 10^{13} Btu

	1975		1980		1985		1990		1995	
Los Angeles	B	E	B	E	B	E	B	E	B	E
Gas	7.63	7.63	8.06	5.72	8.47	3.82	8.90	1.91	9.36	0.
Electric	.24	.24	.31	4.51	.41	8.78	.54	13.10	.68	17.5
Denver										
Gas	.86	.86	.90	.65	.95	.43	1.00	.22	1.05	0.
Electric	.13	.13	.17	.43	.73	.75	.32	1.10	.44	1.49
St. Louis										
Gas	1.35	1.35	1.40	1.01	1.45	.68	1.50	.34	1.55	0.
Electric	.41	.41	.55	1.86	.72	2.34	.93	3.31	1.19	4.36
LPG	.10	.10	.12	.07	.15	.05	.18	.02	.21	0.

B = Baseline E = Electrification

electric water heating for all new housing units. The baseline and scenario energy use are also presented in Table 18.

Cooking and Clothes Drying

The electrification scenario for cooking and clothes drying is the same as the previously discussed residential electrification scenarios and the pertinent data are presented in Table 19.

ELECTRIC CAR

In the transportation sector, scenarios were developed for each region in which gasoline-powered light duty motor vehicles were replaced by electric battery-powered vehicles. Before describing the scenarios in detail, it is worth reiterating that our primary motivation in constructing scenarios was to estimate upper bounds upon both the air quality effects and the amount of petroleum fuel saved. Consequently, the electric car scenarios attempted to estimate the maximum amount of electric car usage that was technologically feasible for the time periods while meeting certain assumptions regarding driver behavior in the regions. If the results of this limiting case (the most favorable for savings of gasoline and the least favorable with regard to regional air quality) fail to produce any significant changes, then it can be concluded that smaller perturbations in the assumptions, which were highly uncertain to begin with, will not produce significant effects either.

Detailed scenarios of future electric car usage in the Los Angeles region have been the subject of a published EPA report by General Research Corporation (GRC) [51]. The purposes of the GRC scenarios were different from the current study; they attempted to make estimates of the most likely levels of electric car usage. Therefore, the results of our scenarios differ considerably from those prepared by GRC.

However, the present study was able to draw upon the extensive research on the electric car conducted by GRC and utilize a number of inputs derived by GRC from primary data sources, such as the Los Angeles Area Regional Transportation Study (LARTS) [13].

TABLE 19

COOKING AND DRYING SCENARIO
FOR RESIDENTIAL/COMMERCIAL SECTOR

Energy Consumption - 10^{12} Btu

	1975		1980		1985		1990		1995	
Los Angeles	B	E	B	E	B	E	B	E	B	E
Gas	32.37	32.37	34.17	24.28	35.92	16.18	37.77	8.09	39.71	0.
Electric	2.78	2.78	3.51	15.44	4.72	28.52	6.42	41.9	7.75	55.6
Denver										
Gas	1.91	1.91	2.01	1.43	2.11	.96	2.22	.48	2.33	0.
Electric	4.17	4.17	5.67	6.36	7.62	9.01	10.49	12.59	14.46	17.3
St. Louis										
Gas	5.69	5.69	5.89	4.27	6.10	2.84	6.32	1.48	6.54	0.
Electric	4.48	4.48	5.96	8.23	7.84	12.52	10.06	16.98	11.92	21.05
LPG	.49	.49	.60	.37	.73	.25	.87	.12	1.03	0.

B = Baseline E = Electrification

Basically, the principal factor in determining how many vehicles can be converted to electric cars in a future period is the driving range of the electric car between battery recharges. Following the GRC assessment of the state of development of battery-powered electric cars, it was assumed that a four-passenger electric car with lead-acid battery and a maximum daily cruising range of 55 miles per day would be available by 1980, and an advanced nickel-zinc battery system with a cruising range of about 150 miles per day would be available by 1990. Both of these vehicles have performance characteristics, such as acceleration and speed, that would meet most urban driving requirements and, in addition, possess passenger comfort and safety features that are comparable to today's compact cars. For detailed operating characteristics of these prototype vehicles, refer to the GRC Task Report by Friedman, Ardon and Hamilton [51].

The ultimate objective in developing alternative scenarios was to estimate the proportion of annual vehicle miles traveled which can be assigned to the electric car. Essentially, the general approach was to first estimate the percentage of driver trips that were less than, or equal to, the assumed range of the electric car in a given year. The corresponding percentage of vehicle milestraveled, accounted for by the percentage of drivers, was then determined by employing the cumulative distribution of VMT by drivers in the population.

By contrast, the GRC scenarios basically assumed that lead-acid battery electric car use, at least in Los Angeles, would be restricted to the second most frequently driven car in multiple car households. Second, the use would also be limited to those households with off-street parking facilities which were assumed the only type that could accommodate recharging equipment. The electrification scenario used in this study did not assume these factors as limiting.

Since the only analysis of driving behavior available was for the Los Angeles region, the estimates for all of the regions are based on the adjusted frequency distributions of trip lengths for Los Angeles. This distribution did not differ from data collected for other selected regions,

so its application to Denver and St. Louis appears plausible. However, it is recommended that this assumption should be further examined.

The actual electric car penetration estimates are reached as follows. First, the cumulative distribution of distance traveled per day, derived from the 1967 LARTS survey, was increased to account for two factors: (1) conversion of direct point-to-point distances as reported in the survey to estimate road mileages (23 percent adjustment), and (2) to account for under-reporting of distances traveled (as calibrated to other surveys in the area), an additional 37 percent adjustment. These adjustments reduced, for a fixed mileage, the cumulative percentage of vehicles which traveled the given distance on a typical day. The updated mileage distribution is shown in Figure 11. The range of both the lead-acid battery electric automobiles has been superimposed on the diagram for reference.

Second, the distribution of VMT by vehicles, i.e., the cumulative percentage of VMT accounted for by the cumulative percentage of vehicles driven, was utilized to relate the number of vehicles driving less than a given distance to cumulative VMT. The distribution used is depicted in Figure 12. It should be emphasized that fuel consumption and emissions are directly related to VMT.

It was assumed that electrics could be introduced at a rate commensurate with their direct technical substitution. That is, a fleet of electric cars with a given range could replace all conventionally powered vehicles that travel less than the stated distance on a daily basis. For example, a lead acid electric with a range of 55 miles could replace 80 percent of the conventionally powered light duty vehicles on the road. This corresponds to a 62 percent reduction in VMT as per Figure 12.

Table 20 shows the substitution data used in the electric car scenario. The introduction of the advanced battery electric and replacement of IC vehicles was phased over a 10 year period. The 1985-1990 estimates represent a transition between lead-acid and advanced battery with an approximate 50-50 mix. By 1995, all electrics would be of the advanced type.

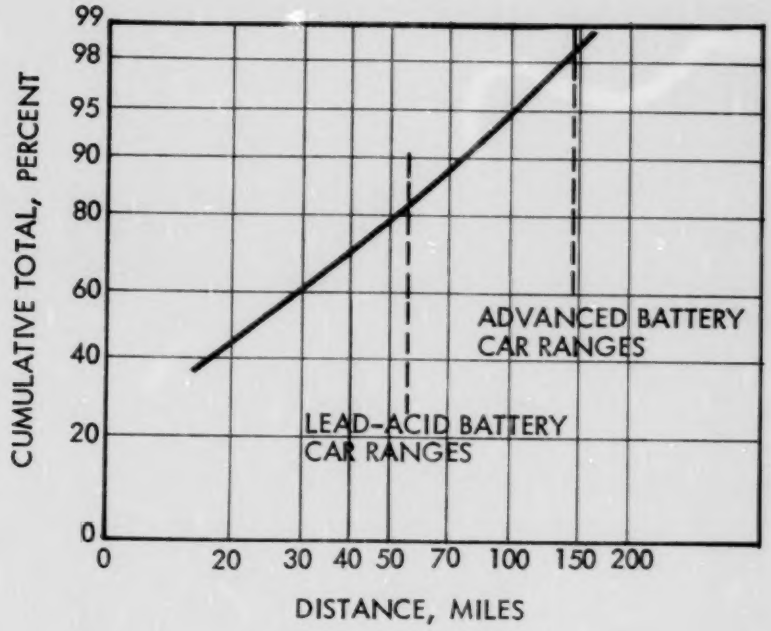


Figure 11. Daily Distribution of VMT

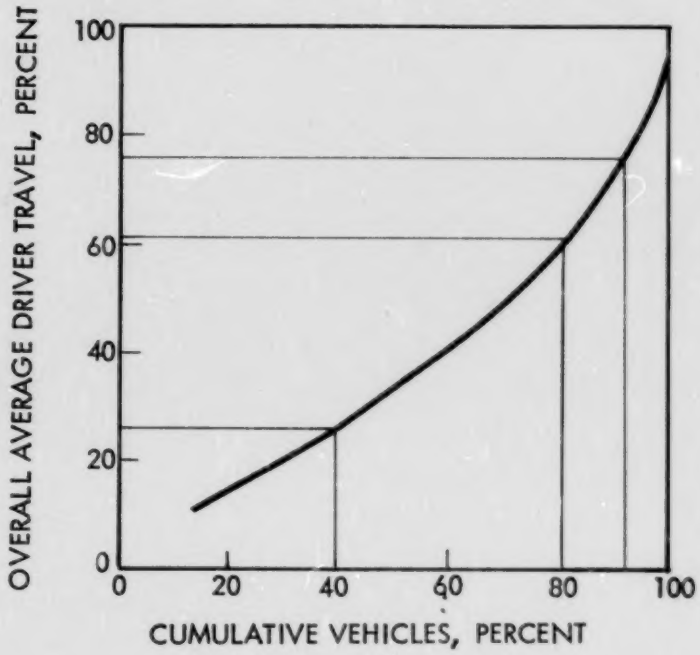


Figure 12. Distribution of VMT by Vehicles

TABLE 20
CHARACTERISTICS OF ELECTRIC CAR
SCENARIO

	LEAD ACID		ADVANCED BATTERY	
	1975-1980	1980-1985	1985-1990	1990-1995
	%	%	%	%
Vehicles Replaced	80	80	90	98
VMT Reduced	62	62	78	96

Projected Energy Growth

The three panels in Figure 13 depict energy growth factors for motor vehicles over time in the three study regions with and without the electric car. Without the electric car, total energy consumption by motor vehicles is synonymous with gasoline consumption. This quantity increases steadily over time in Denver due to the strong uptrend in VMT in this region. In St. Louis total gasoline consumption dips slightly in the 1975-1980 interval as fuel economy factors (including shifts in the vehicle mix toward lighter cars) swamp the mild uptrend in VMT, but the VMT effects take over for the remainder of the period. In Los Angeles total gasoline consumption falls steadily over time due to the interaction of fuel economy with a slight projected increase in VMT. Total energy saving in this sector due to the electric car comes to the fore after 1985 in all three regions. In the Denver and St. Louis regions, total energy consumption by motor vehicles actually increases without the electric car, while a slight downtrend occurs in the Los Angeles region. Prior to that year, total energy consumption with the electric car increases relative to the baseline scenario. In all three regions there is a dramatic downtrend in the regional consumption of gasoline when the electric car scenarios are in force.

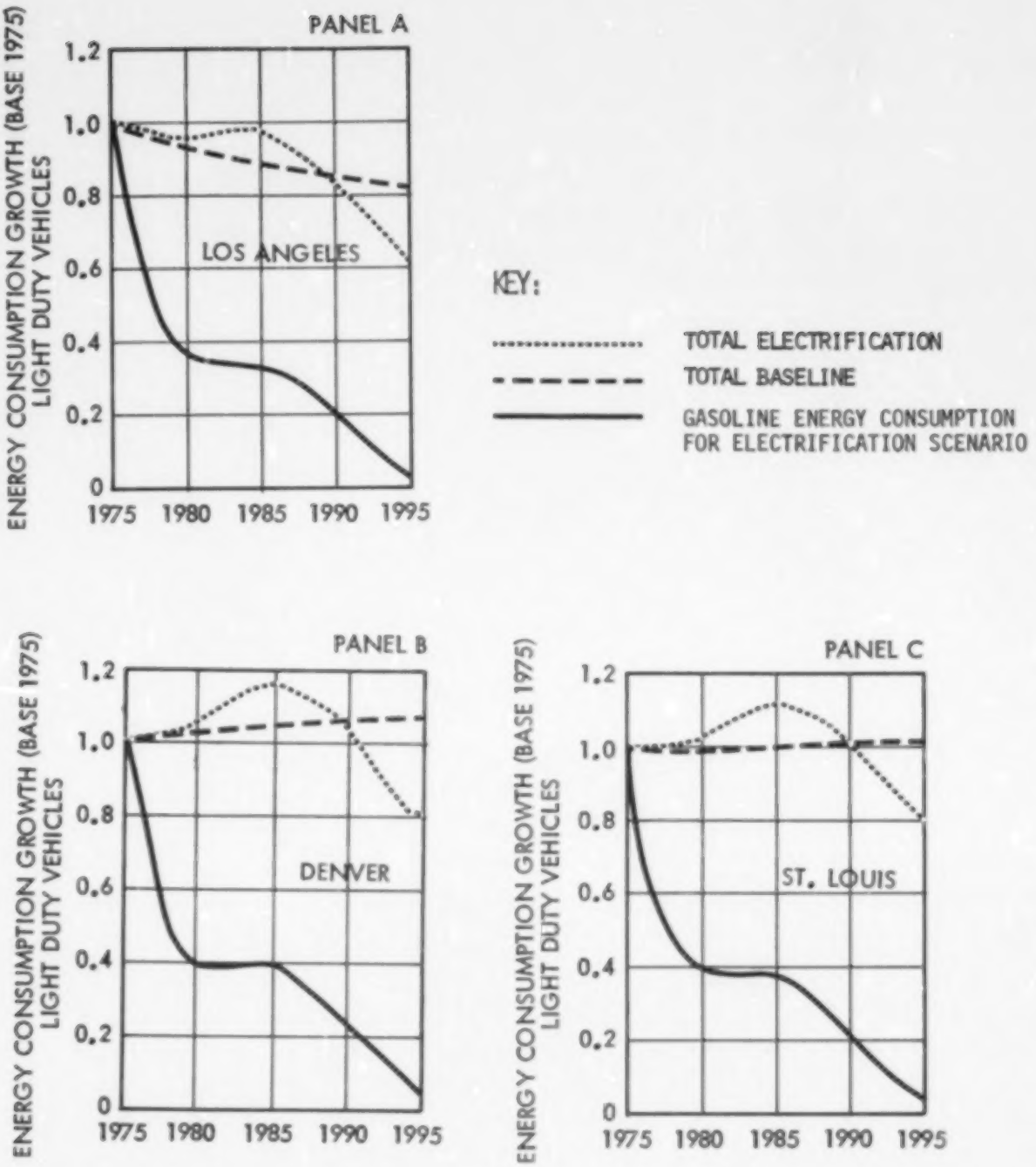


Figure 13. Forecast of Energy Consumption in Transportation

Forecast Energy End Use Consumption

Table 21 features forecast energy end use consumption data for both the baseline and electrification scenarios. The significance of these results is that while energy consumed in transportation is estimated to decrease as a result of electrification this reduction is more than offset by the substantial energy growth in the residential/commercial sector. It should be reemphasized that the introduction of electrics for this study has been limited to light duty vehicles. The potential for application of electrics to other types of vehicles should be examined.

The largest increase in energy growth is predicted for St. Louis followed closely by Denver. In terms of differences between the two scenarios, the greatest change is also observed for St. Louis. It can be concluded that St. Louis has a higher potential for electrification than either Denver or Los Angeles.

TABLE 21.

FORECASTED ENERGY END USE CONSUMPTION BY SECTOR*
(10^{14} BTU) 1995

BASELINE	TRANSPORTATION		RESIDENTIAL/COMMERCIAL		INDUSTRIAL		TOTAL	GROWTH (1975-1995)
Los Angeles	5.3639	(29%)	8.4568	(46%)	4.5304	(25%)	18.351	+29.7%
Denver	.6304	(24%)	1.4515	(55%)	.5695	(21%)	2.651	+37.8%
St. Louis	1.1082	(20%)	3.1306	(56%)	1.3126	(24%)	5.551	39.5%
ELECTRIFICATION								(Elec)/(Base)
Los Angeles	4.321	(21%)	11.4662	(56%)	4.5304	(22%)	20.3176	+10.7%
Denver	.5026	(17%)	1.8036	(63%)	.5695	(20%)	2.875	+ 8.4%
St. Louis	.8832	(14%)	4.1992	(66%)	1.3126	(20%)	6.395	+15.2%

* Percentage figures in parantheses are in terms of total. The growth data indicates the percentage change in baseline energy use between 1975 and 1995, and the difference between the baseline and electrification scenarios.

SECTION VII

AIR QUALITY IMPACT OF INCREASED ELECTRIFICATION

Two approaches were utilized in attempting to measure the impact of increased electrification on air quality. First, the total change in regional emissions for each of the pollutants was assessed. Secondly, the Climatological Dispersion Model (CDM) and rollback were used to evaluate corresponding air quality.

EMISSIONS

Figure 14 indicates the relative change in mobile source emissions between 1975 and 1995 for the two scenarios examined. Two interesting trends seem to emerge from these forecasts. First, emissions from mobile sources for all three regions will, by 1995, constitute a substantially smaller percentage of the total than in 1975 (in most cases less than 25 percent). Second, the relative impact of the electrification scenario on mobile emissions in 1995 appears to further reduce the contribution of mobile emissions on all pollutants in each region. Significant improvements are achieved in particulate emissions, particularly in the Los Angeles region. These observations will be discussed in more detail below. It should again be noted that the three study region's dependence on natural gas as a fuel has a substantial effect on the emission characteristics of the regions with regard to electrification.

Hydrocarbons -

Total regional hydrocarbon emissions decrease for both the baseline and electrification scenario in all three regions during the twenty year study period as indicated in Figure 15. Hydrocarbon emissions for the baseline in 1995 are reduced the most in the Los Angeles region (to 36% of the 1975 emissions), and the least in the St. Louis region (to 80% of 1975 emissions). For the electrification scenario, the impact is similar for the three regions,

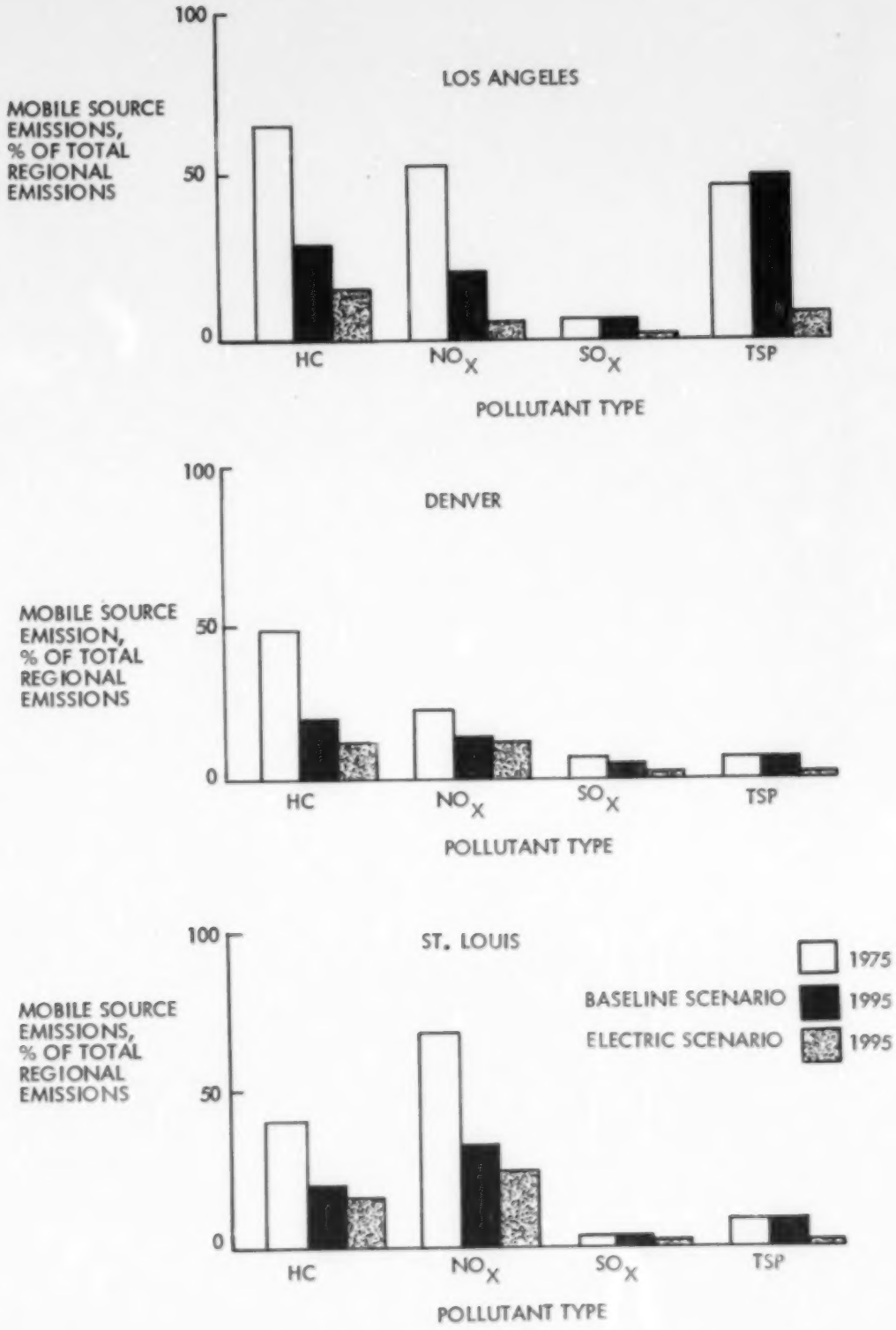


Figure 14 Comparison of Mobile Source Emission Contribution by Region

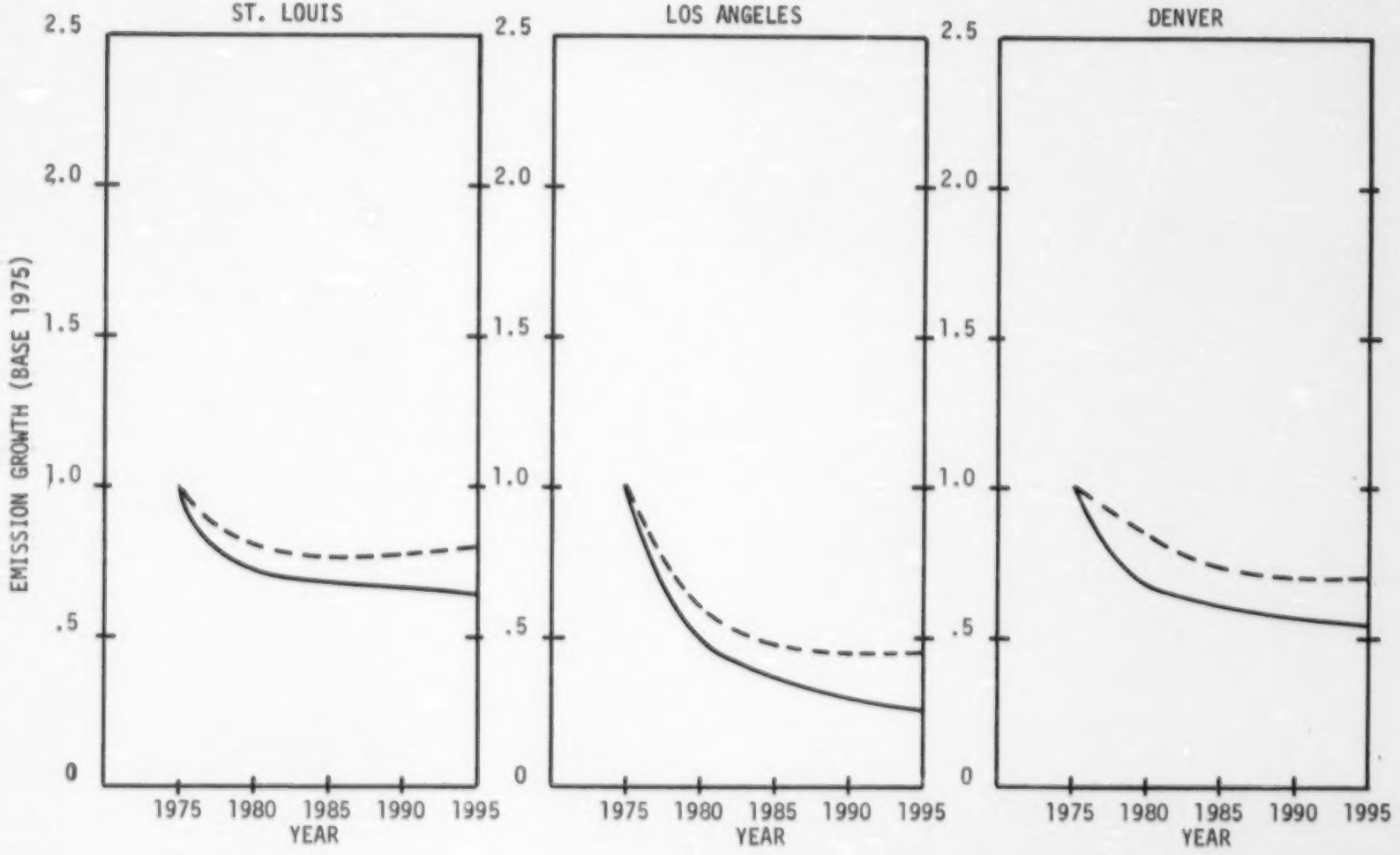


Figure 15 Forecasted Hydrocarbon Emission Growth Factors

where an additional 15% reduction in hydrocarbon emissions is achieved.

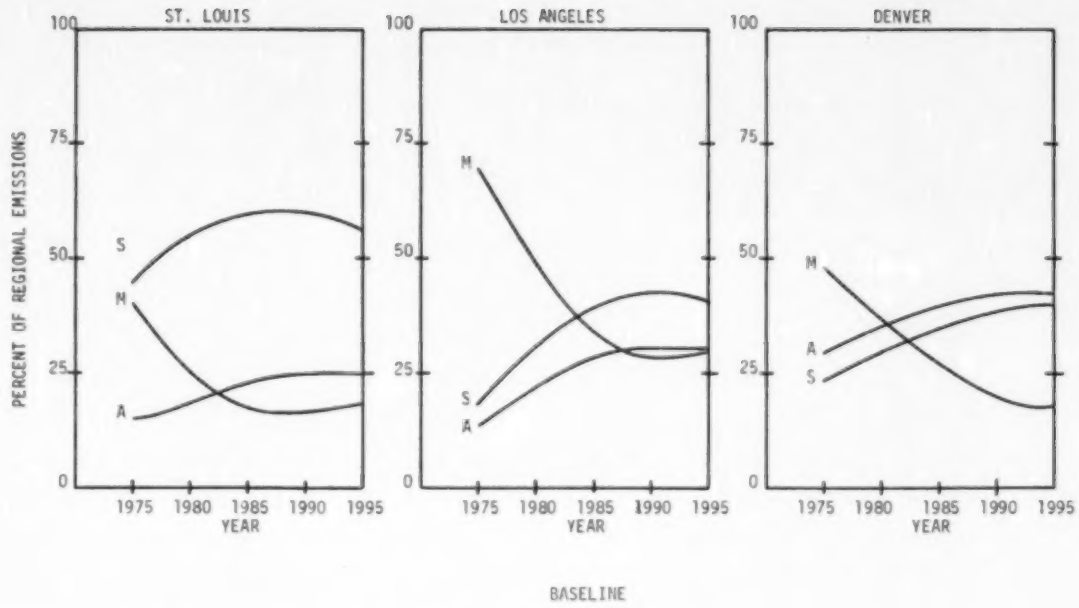
The overall decrease in the baseline hydrocarbon emissions in the three areas by 1995 can be attributed to the reduced contribution of mobile sources to the regional emissions as indicated in Figure 16. This is brought about by the implementation of motor vehicle controls by 1995. The greater initial contribution of mobile source emissions in the Los Angeles region as compared to the St. Louis region (stationary point sources actually contribute a greater percentage to the total regional emissions) accounts for the significant difference in the reduction of hydrocarbon emissions over the twenty year study period.

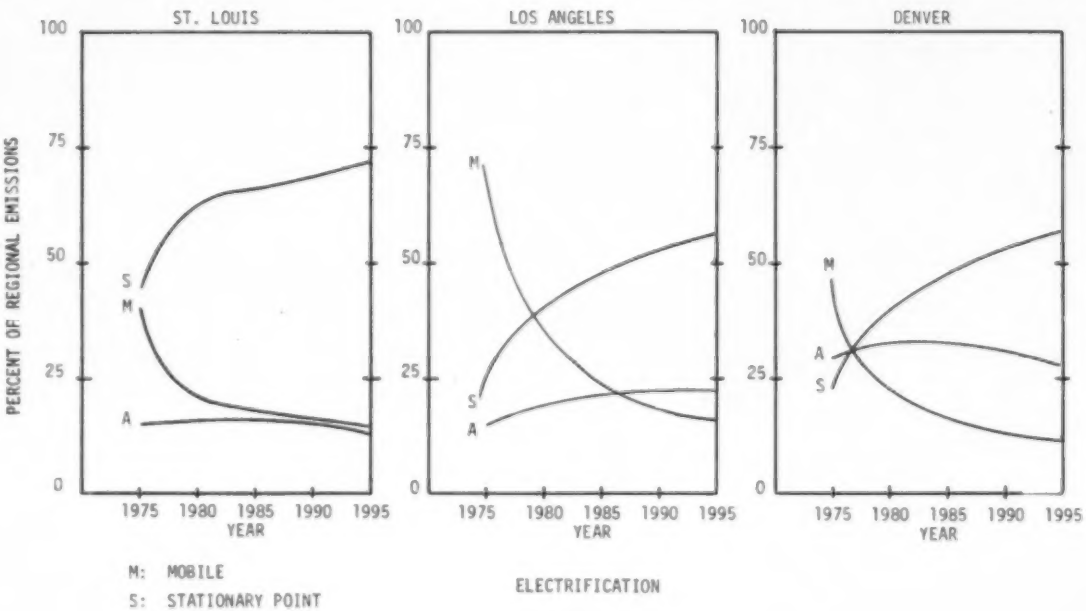
The primary impact of electrification on hydrocarbon emissions is to further reduce the mobile source emissions. In addition, evaporative hydrocarbon emissions due to gasoline storage and marketing (included in stationary area sources) are reduced to reflect the decrease in gasoline usage for the electrification scenario. The net effect is to reduce mobile and area source contributions so that stationary point sources are the dominant emissions in each area.

NO_x -

In the Los Angeles and St. Louis regions, total NO_x emissions decrease for both the baseline and electrification scenarios for the twenty year study period, Figure 17. The primary cause for reduction in total regional NO_x emissions is the decrease in mobile emissions. As indicated in Figure 18, the baseline forecast is for the contribution of stationary sources to increase considerably in St. Louis and Los Angeles due to mobile source reductions, while in Denver, where NO_x from mobile sources is not as significant, stationary source emissions still dominate the regional emissions and results in a net increase in NO_x emissions.

The basic effect of electrification, Figure 18, in each study region is to reduce mobile and stationary area source emissions with no change in stationary point source emissions. Since stationary point sources are the dominant category in each region by 1995 (because of the new car NO_x controls),





M: MOBILE
S: STATIONARY POINT
A: STATIONARY AREA

Figure 16. HC Emission Distribution by Source

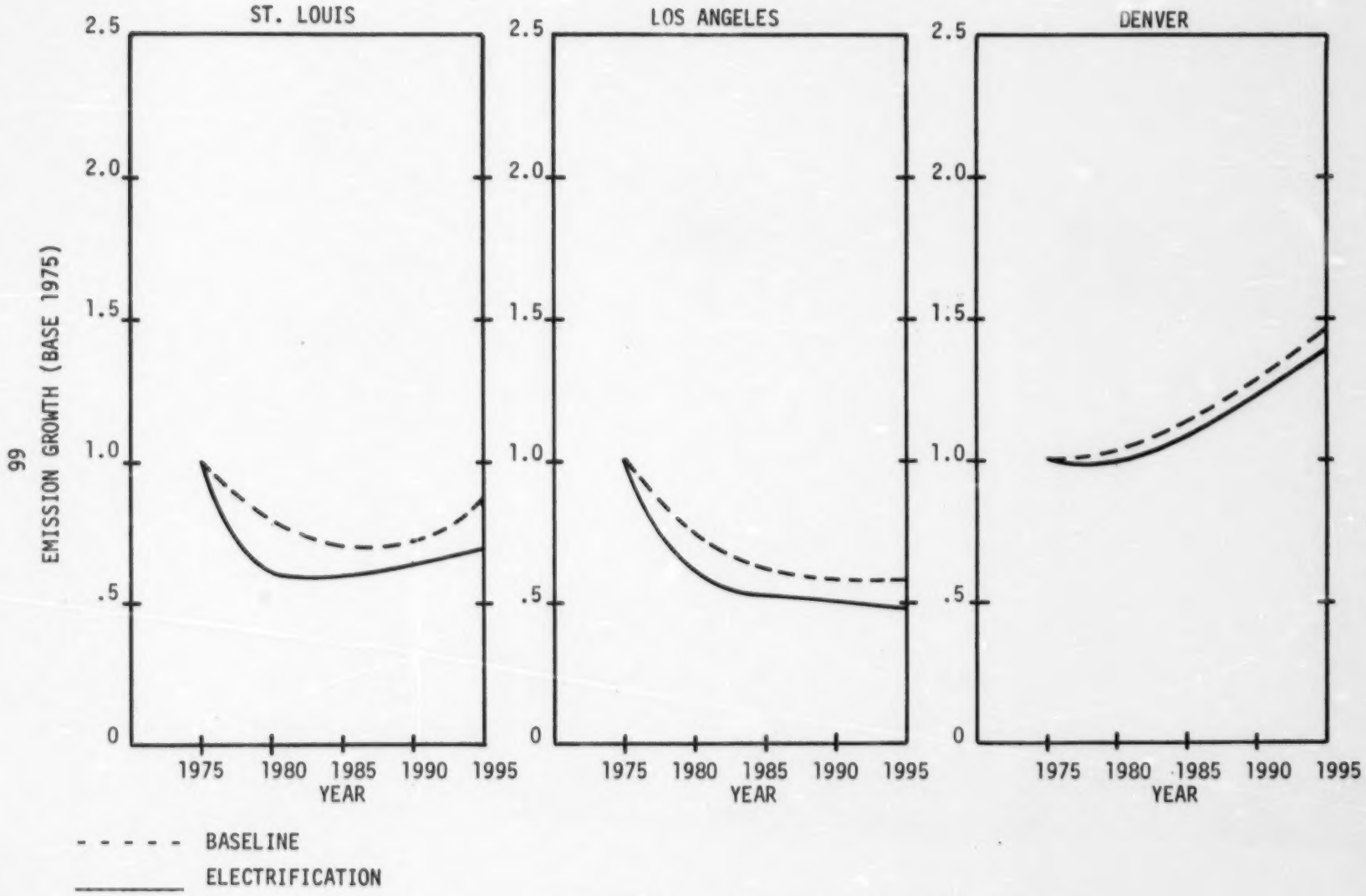


Figure 17 Forecasted NO_x Emission Growth Factors

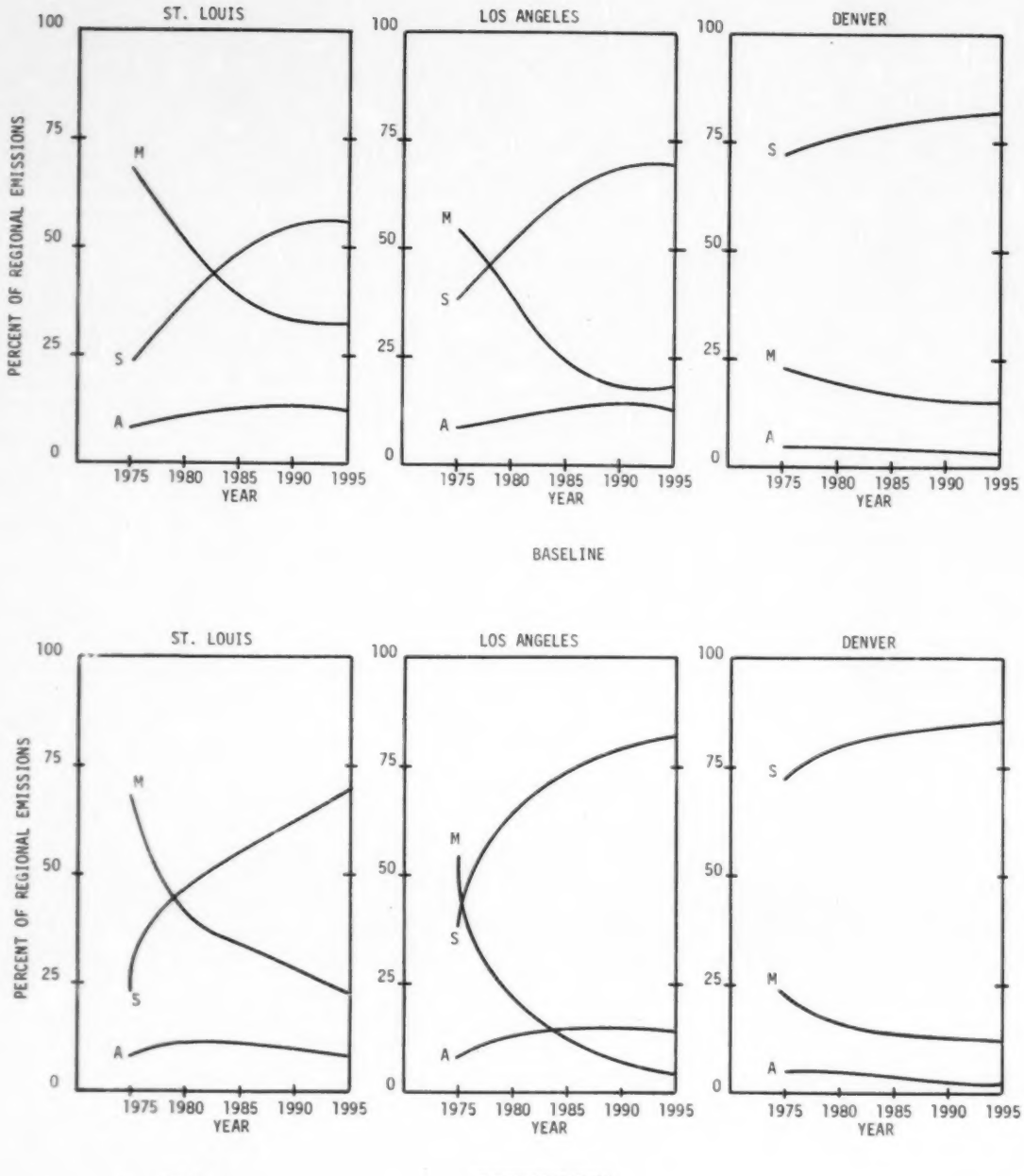


Figure 18. NO_x Emissions Distribution By Source

the reduction in mobile and stationary area sources due to electrification has a moderate (5-15%) effect on total NO_x emissions in 1995. This effect is the least in the Denver region because of the small contribution from mobile and stationary area sources to total regional NO_x emissions.

SO_x -

Stationary point sources dominate the SO_x emission inventory in each region. Due to the increased use of coal fired electrical generation, SO_x emissions from stationary point sources will increase considerably in St. Louis and Denver. Point source emissions in Los Angeles, where no increase in coal usage is forecasted, remain approximately the same. Figures 19 and 20 indicate these trends.

The basic impact of increased electrification in the three regions is to reduce SO_x emissions from mobile and stationary area sources with no change in stationary point sources. Since stationary point sources are by far the dominant SO_x source category, electrification has little impact on SO_x emissions.

Particulates -

Stationary point sources dominate the particulate emissions in Denver and St. Louis and, with the increase of coal fired electrical generation in these regions, significant increases in particulate emissions are forecasted, Figure 21. Mobile sources are relatively more important in Los Angeles; thus, with no major point source increases, only a slight increase in regional particulate emissions is forecasted, Figure 22.

Electrification decreases particulate emissions from mobile and stationary area sources, while having no effect on stationary point sources, Figure 22. Since stationary point sources are the dominant source of particulates in Denver and St. Louis, electrification results in moderate (15%) particulate improvements in these regions. Since mobile sources are the dominant source in the Los Angeles region, electrification produces a significant reduction (50%) in particulate emissions in this region.

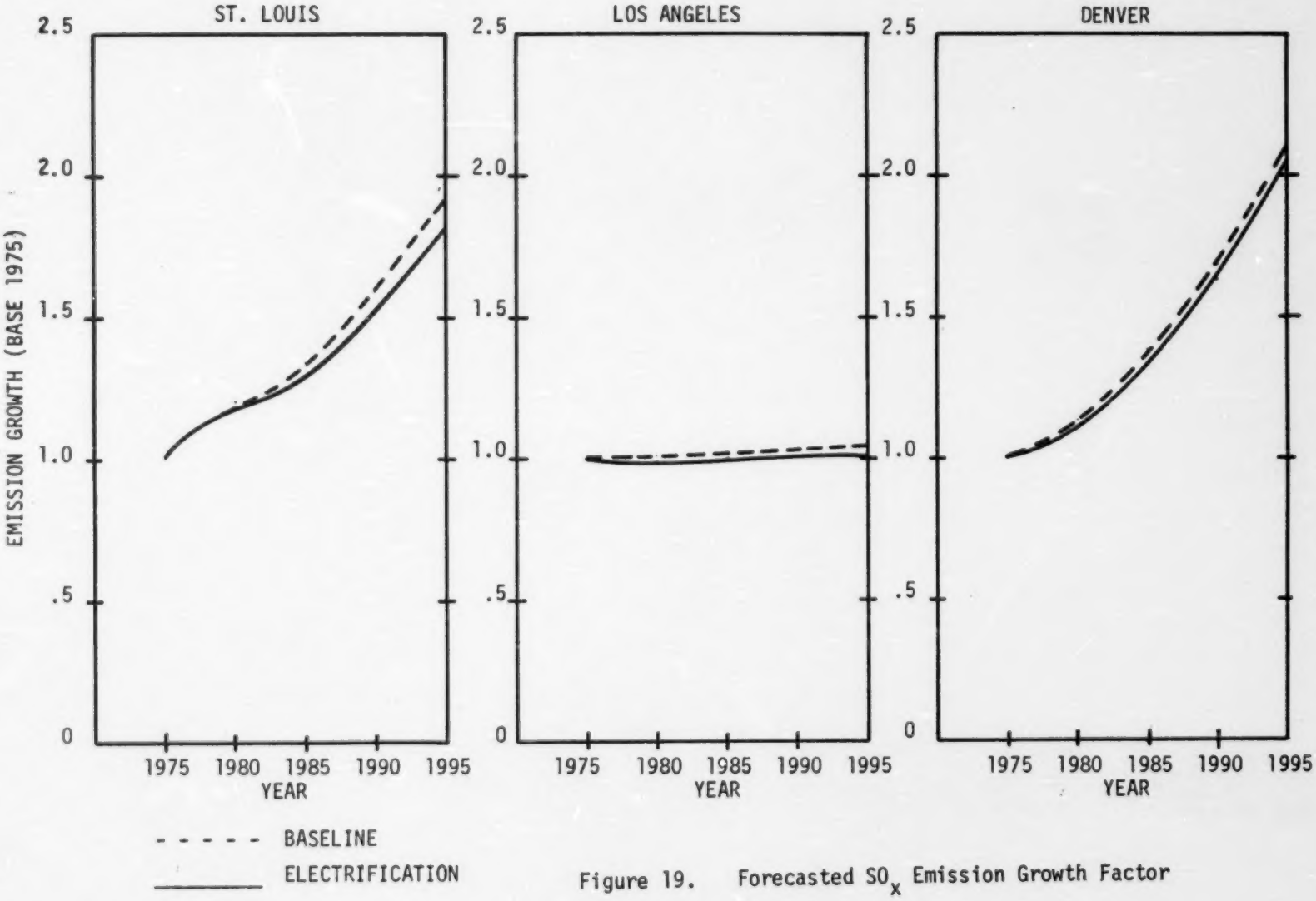


Figure 19. Forecasted SO_x Emission Growth Factor

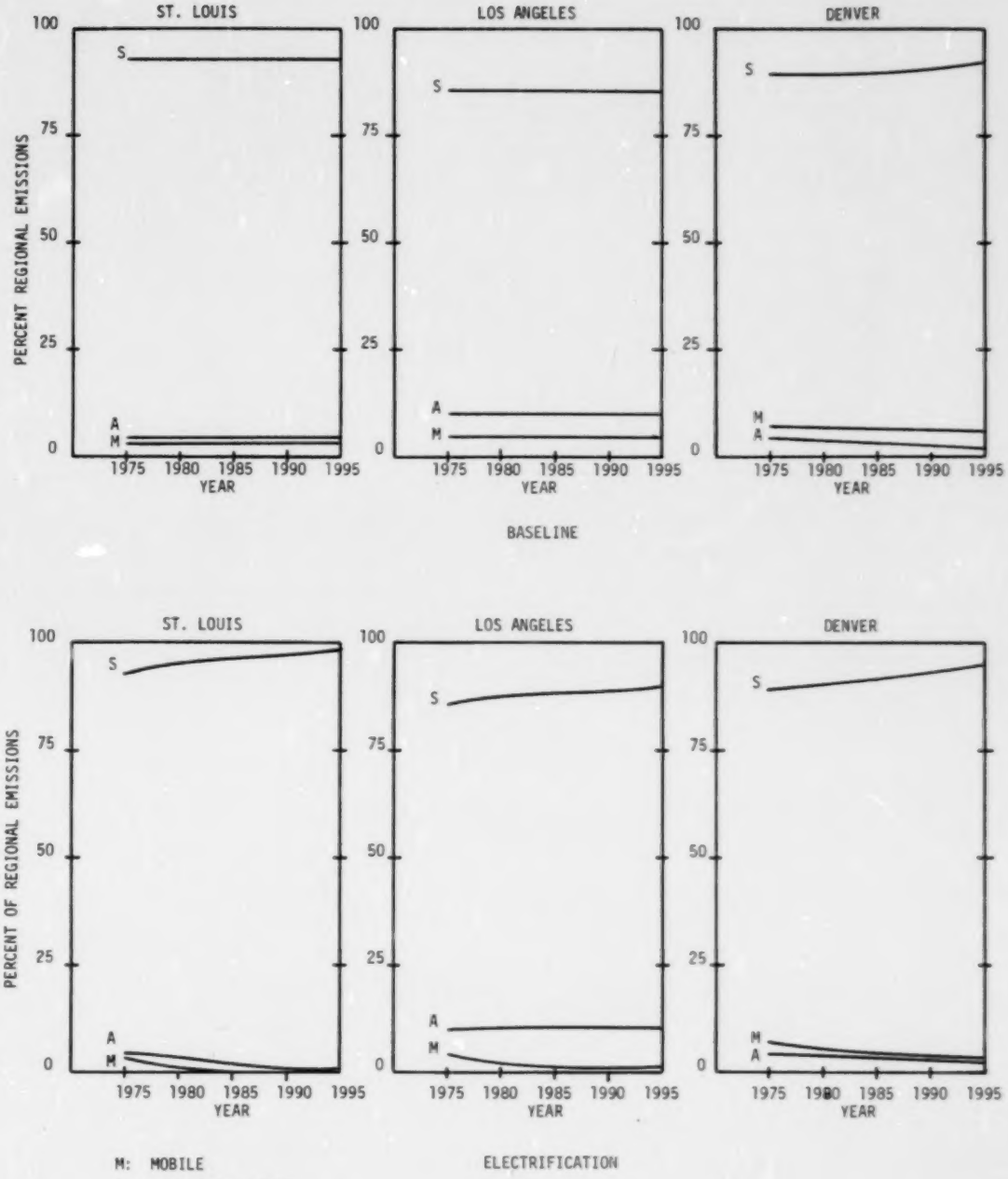


Figure 20. SO_x Emissions Distribution by Source

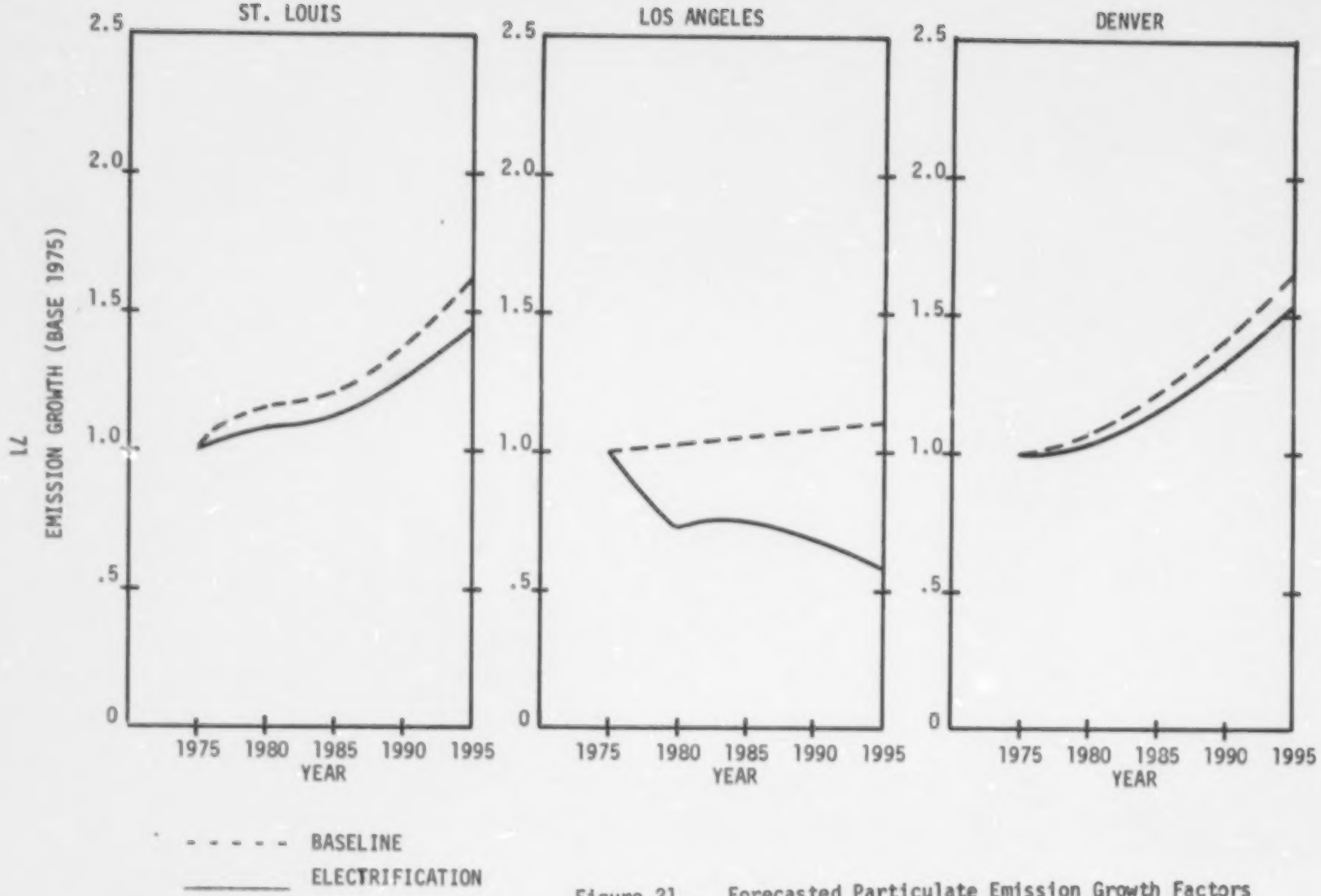


Figure 21. Forecasted Particulate Emission Growth Factors

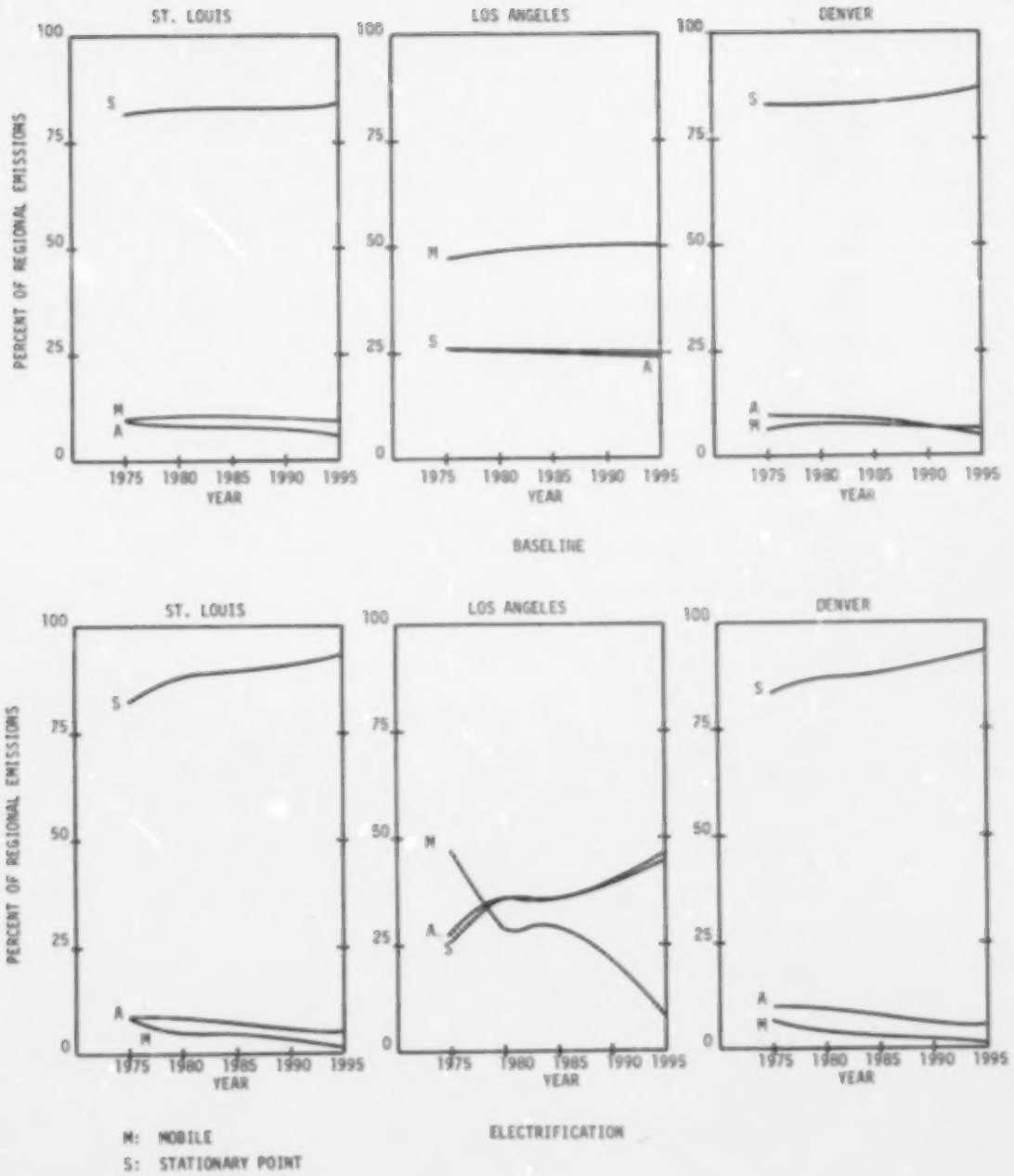


Figure 22. Particulate Emissions Distributed by Source

AIR QUALITY

The CDM program was used to determine air quality for NO_2, SO_2 and particulates. This model computes long-term average concentrations on an urban scale from numerous point and area sources. CDM simulates the effects of yearly meteorological conditions by use of a stability wind rose for the frequency of joint occurrence of different wind speeds, directions and atmospheric stabilities.

The rollback methodology discussed earlier was used to estimate maximum one hour oxidant from regionwide hydrocarbon emissions. St. Louis and Denver data were derived from the standard curve developed by Barth and the Los Angeles data were derived from a curve developed by Schuck and Papetti, (see Figure 2).

In order to arrive at a single measure of the relative impact on air quality of intensive electrification, the average regionwide air quality was determined. This is simply the average of the average concentration in each 10 km square for the defined grid system in each region. Table 22 highlights the impact of both the baseline and electrification scenarios on air quality by using this procedure.

Care should be exercised in deriving conclusions concerning a specific air quality forecast for a given region. The method used in estimating average air quality and the procedure employed in calibrating CDM may uniformly bias the absolute air quality predictions. For comparative analysis, however, this approach appears adequate.

Oxidants

Table 23 presents the forecast trends in HC emissions and the resultant oxidant concentrations for each of the air basins over the study period. As is evident, electrification had its greatest impact on oxidant air quality in Los Angeles where vehicle usage is at the highest level. In Denver and St. Louis, where the impact appears less, mobile source emissions are less important. Nevertheless, oxidant concentrations did decline in each study region.

The most critical feature of the oxidant forecast is that the oxidant reduction is much smaller than the corresponding reduction in HC emissions

TABLE 22 SUMMARY OF AIR QUALITY IMPACTS IN 1995*

	OXIDANT %	NO_2 %	SO_2 %	PARTICULATES %
Baseline				
Los Angeles	-45	-16	+ 2	+ 2
Denver	-10	+29	+83	+ 4
St. Louis	- 8	- 6	0	+ 9
Electrification				
Los Angeles	-52(18)**	-19(2)	- 6(7)	-15(17)
Denver	-21(25)	+22(5)	+73(6)	+ 3(1)
St. Louis	-19(20)	- 8(2)	0(1)	0(8)

* Estimates are given in terms of percentage difference from the 1975 baseline. A negative value indicates a decrease in average concentration levels while a positive value indicates a corresponding increase.

** Numbers in parenthesis are percent change in concentrations relative to baseline. A positive value indicates a further improvement in air quality.

TABLE 23

FORECASTED OXIDANT AIR QUALITY AND HYDROCARBON EMISSION TRENDS

PPM (HC - TONS/DAY)

	1975	1980	1985	1990	1995	% Change 1975-1995
LOS ANGELES						
o Baseline	0.56 (1055)	0.39 (647)	0.33 (496)	0.31 (464)	0.31 (472)	-45
o Electrification	0.56 (1055)	0.33 (496)	0.30 (430)	0.28 (400)	0.27 (389)	-52
DENVER						
o Baseline	0.29 (209)	0.27 (175)	0.26 (154)	0.26 (143)	0.26 (144)	-10
o Electrification	0.29 (209)	0.26 (152)	0.24 (131)	0.23 (114)	0.23 (108)	-21
ST. LOUIS						
o Baseline	0.37 (407)	0.34 (329)	0.33 (306)	0.33 (313)	0.34 (326)	-8
o Electrification	0.37 (407)	0.32 (288)	0.32 (278)	0.30 (269)	0.30 (262)	-19

This is due to the concavity of the Schuck and Papetti and the Barth curves, which relate HC emissions and oxidant air quality (see Figure 2). The slopes of the curves are very low at these emission levels, which means a large reduction in emissions achieves only a modest improvement in air quality.

NO_x-

In order to convert NO_x emissions to NO_2 concentrations, a conversion factor based on the atmospheric NO_2/NO_x ratio observed in each region was used.

Although the magnitudes of the NO_2 concentrations are reduced on a regionwide basis in the Los Angeles region in the 1995 baseline case, the general air quality pattern remains similar to 1975, (see Figure 23). Heavy concentrations are centered about the downtown Los Angeles area and the San Bernardino area. Electrification produces a much more uniform concentration over the region as a result of the elimination of heavy gasoline vehicular traffic concentrated in the downtown area. The patterns result from uniformly distributed area sources and major point sources (primarily the major power plants, as indicated).

The percent reduction in NO_2 spatial concentrations is presented in Figure 24. As indicated, the greatest improvement occurs in the vicinity of the city of Los Angeles where heavy mobile source emissions are reduced by the substitiution of electric cars for conventional vehicles in this area.

The baseline 1995 case for the Denver region shows a slight increase in the NO_2 concentrations about the downtown Denver and Boulder (southern portion indicated only) due to increased stationary source emissions (primarily coal fired power plant add-ons), (see Figure 25). The concentration patterns remain similar. The electrification scenario has only a modest effect on the air quality patterns.

The percent reduction in NO_2 spatial concentrations is presented in Figure 26. Although large relative reductions are indicated in various areas, the initial concentrations were small, thus causing this effect for small absolute changes.

Figure 23. NO_2 Air Quality Isopleths in Los Angeles

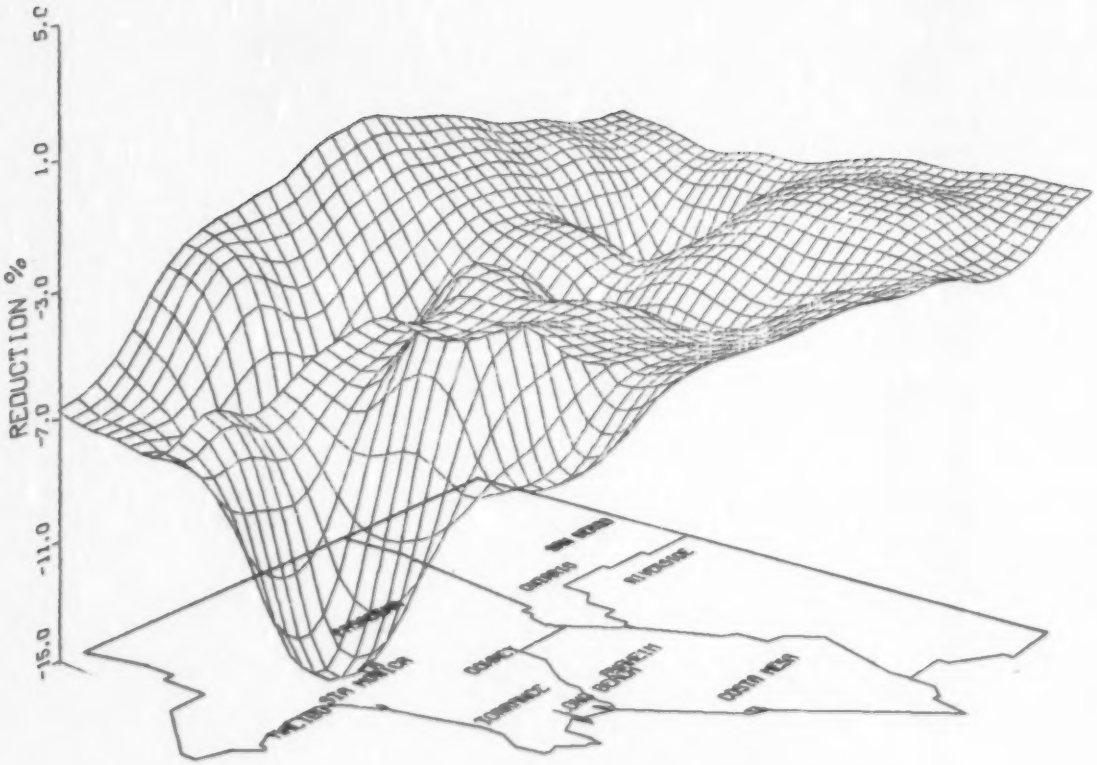


Figure 24

Relative NO_2 Air Quality in Los Angeles - 1995
(Electrification - Baseline)

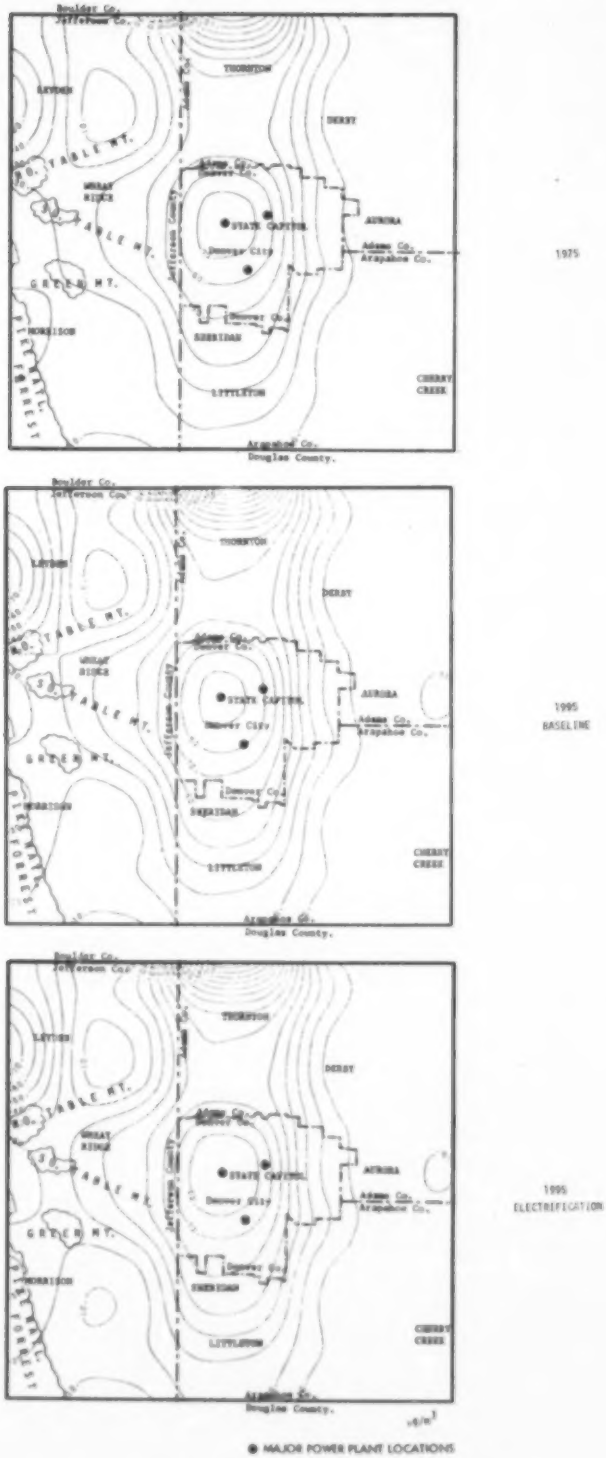


Figure 25. NO_2 Air Quality Isopleths in Denver

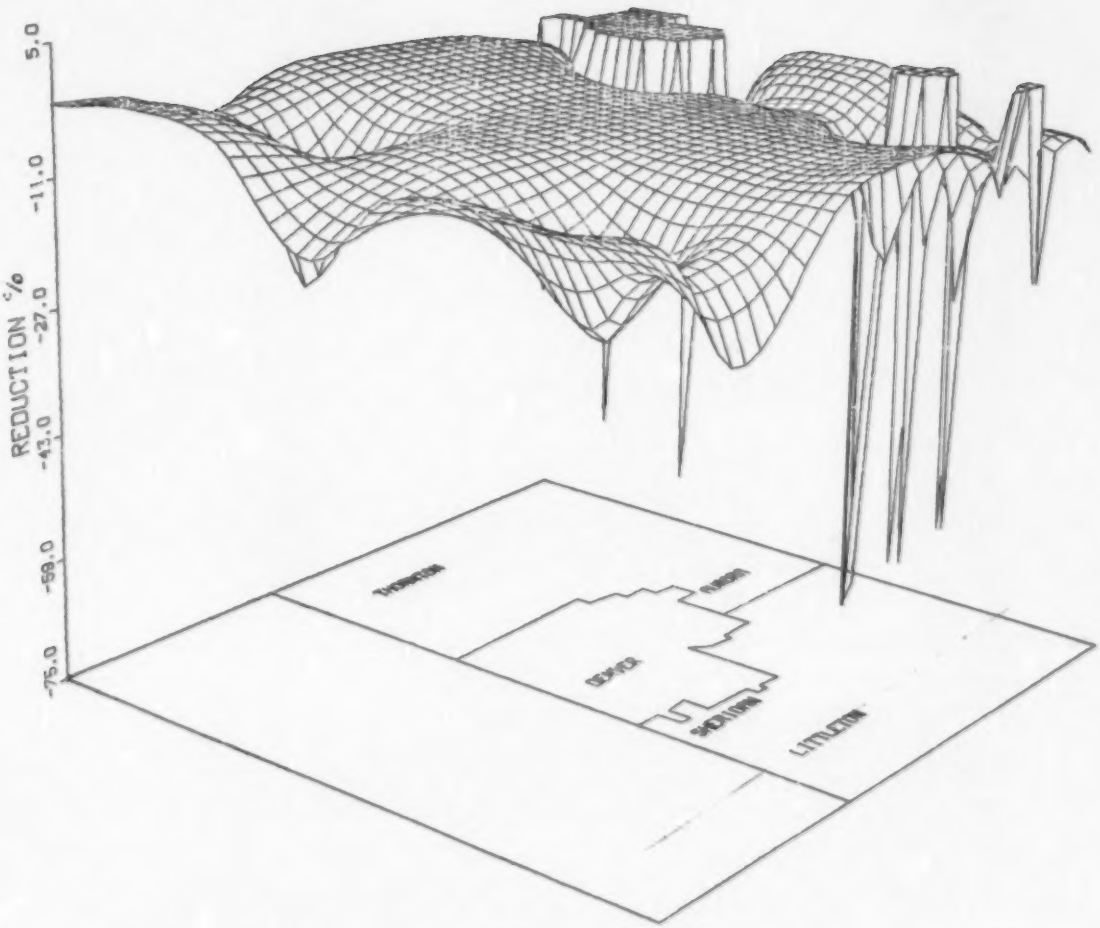


Figure 26

Relative NO_2 Air Quality in Denver - 1995
(Electrification - Baseline)

A slight decrease in NO_2 concentrations about the metropolitan St. Louis area with similar air quality patterns in 1995 is illustrated in Figure 27. This is primarily due to the reduction of mobile source emissions. Electrification, resulting in decreased concentration of mobile emissions in the metropolitan St. Louis area, produces a more uniform area wide air quality pattern.

The relative reduction in NO_2 concentrations illustrated in Figure 28 indicate the predominant impact on the metropolitan St. Louis area due to the substitution of electric cars for conventional vehicles.

The relative change in average regionwide air quality for each of the regions for the study period is presented in Figure 29. These changes closely parallel the changes in total NO_x emissions. However, the air quality predictions tend to be slightly more optimistic than the emission predictions due to the shift from area (ground level) sources to point sources with emission stacks.

SO_2 -

Although there are slight increases in the SO_2 concentration levels in the Los Angeles region about the downtown Los Angeles and San Bernardino areas, the air quality patterns do not change appreciably from 1975 to 1995. The modest reduction in SO_2 concentrations achieved due to electrification results from the reduction of mobile source emissions which only represented a small percentage of the total regional emissions, (see Figure 30). The relative air quality reductions over the region are illustrated in Figure 31. The major reductions occur in the heavy traffic concentration area of downtown Los Angeles where electric cars replace conventional vehicles. The residential/commercial electrification has no effect on SO_2 air quality since Los Angeles is basically a natural gas user.

SO_2 concentrations increase in the Denver region about the major industrial areas although the air quality patterns remain similar, Figure 32. The effect of electrification is negligible as indicated in Figure 33.

Although slight increases are observed in SO_2 concentrations in 1995 in the major industrial areas in the St. Louis region, the air quality

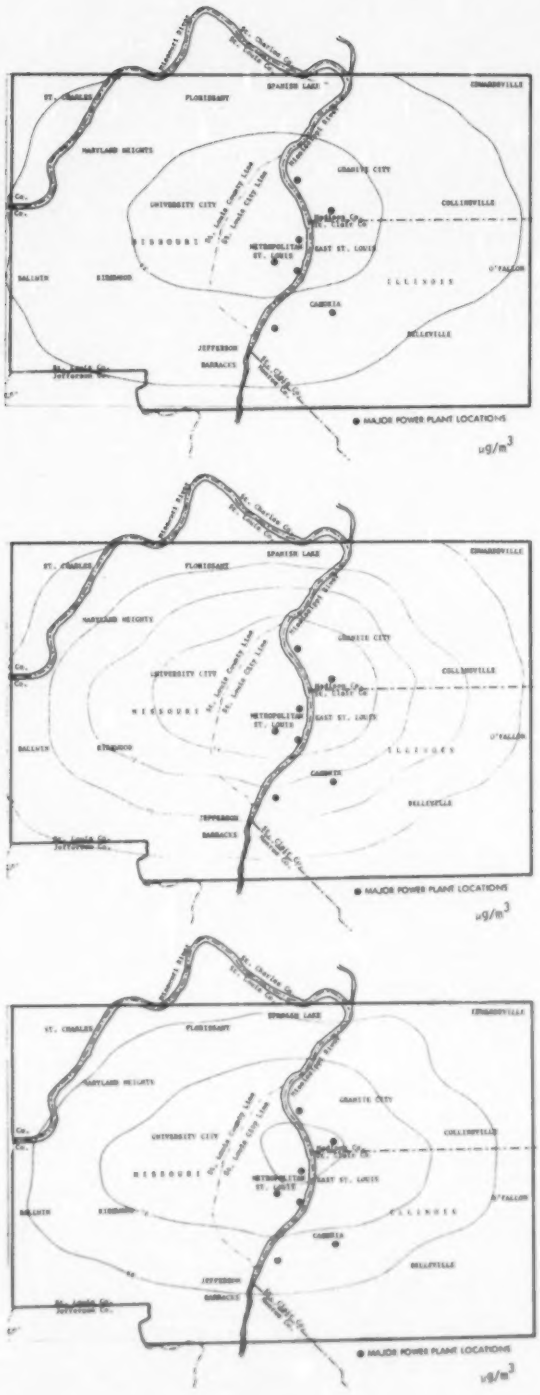


Figure 27. NO_2 Air Quality Isopleths in St. Louis

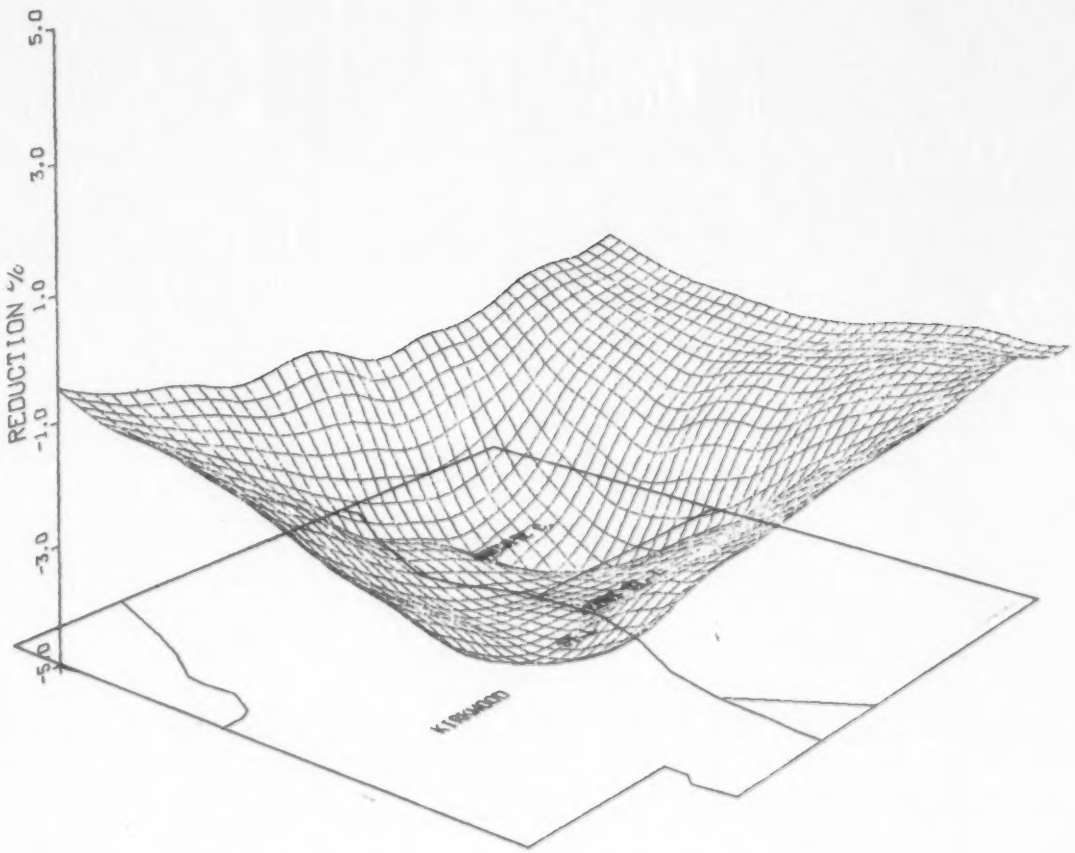


Figure 28

NO_2 Relative Air Quality in St. Louis - 1995

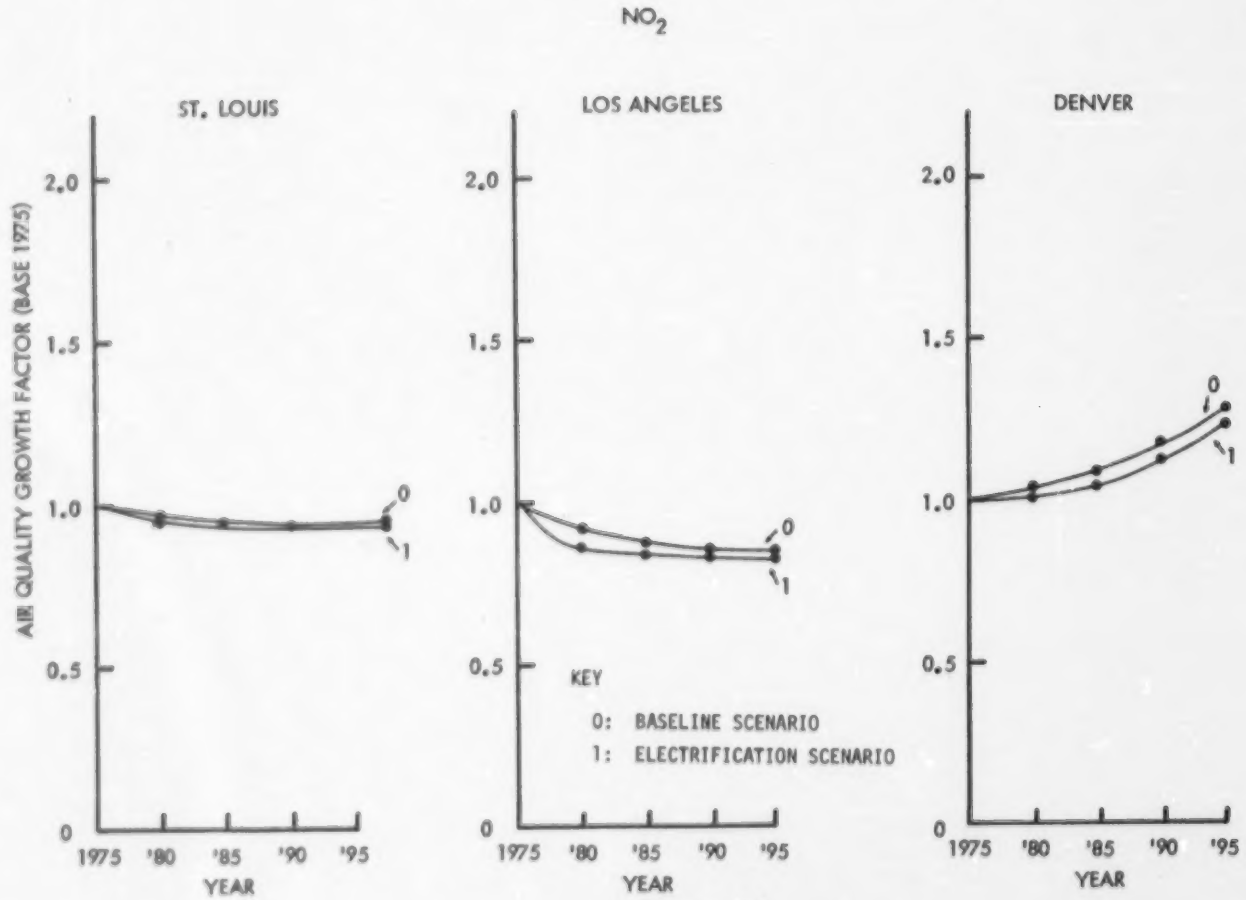
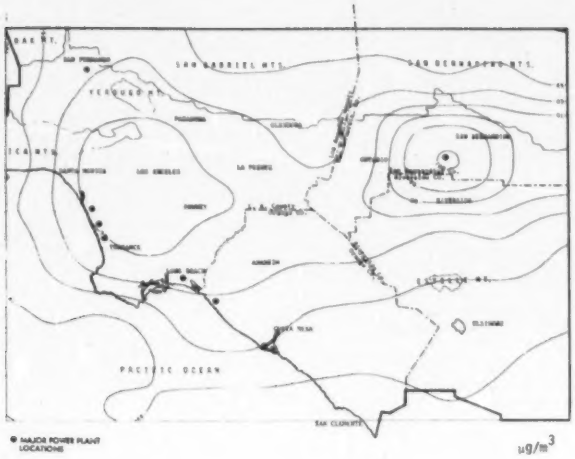
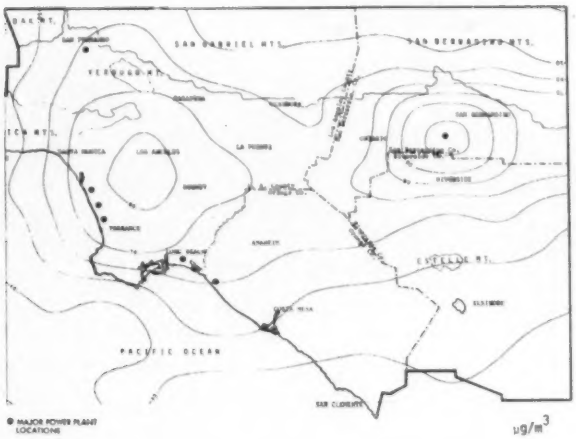


Figure 29

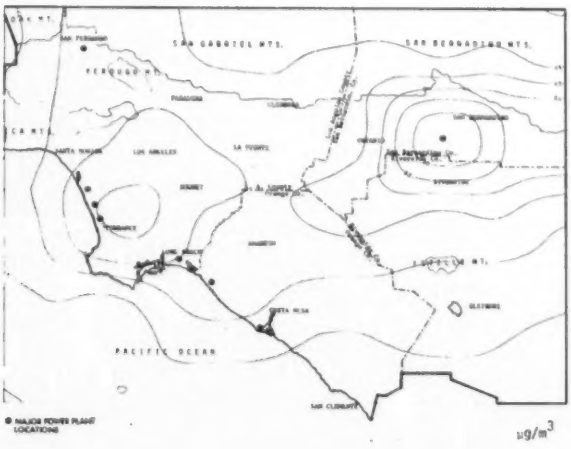
Variations in NO_2 Average Air Quality



1975



1995
BASELINE



1995
ELECTRIFICATION

Figure 30. SO_2 Air Quality Isopleths In Los Angeles

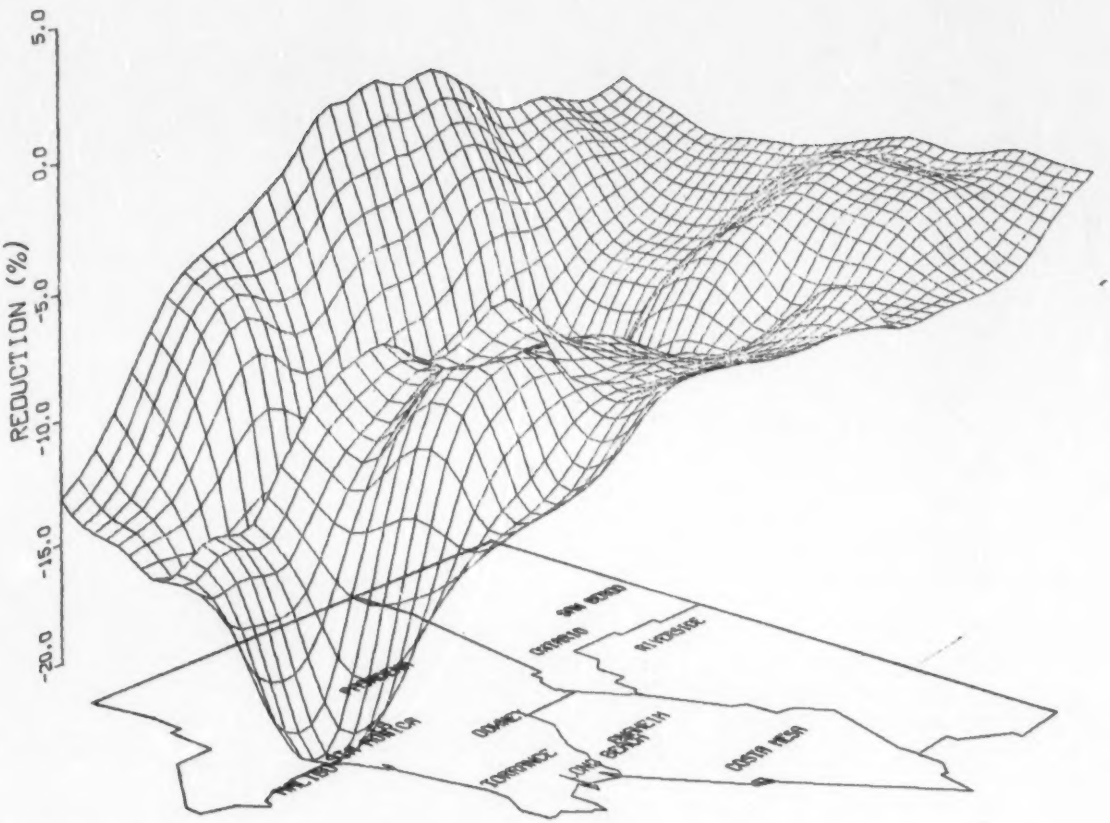


Figure 31

Relative SO_2 Air Quality in Los Angeles - 1995
(Electrification - Baseline)

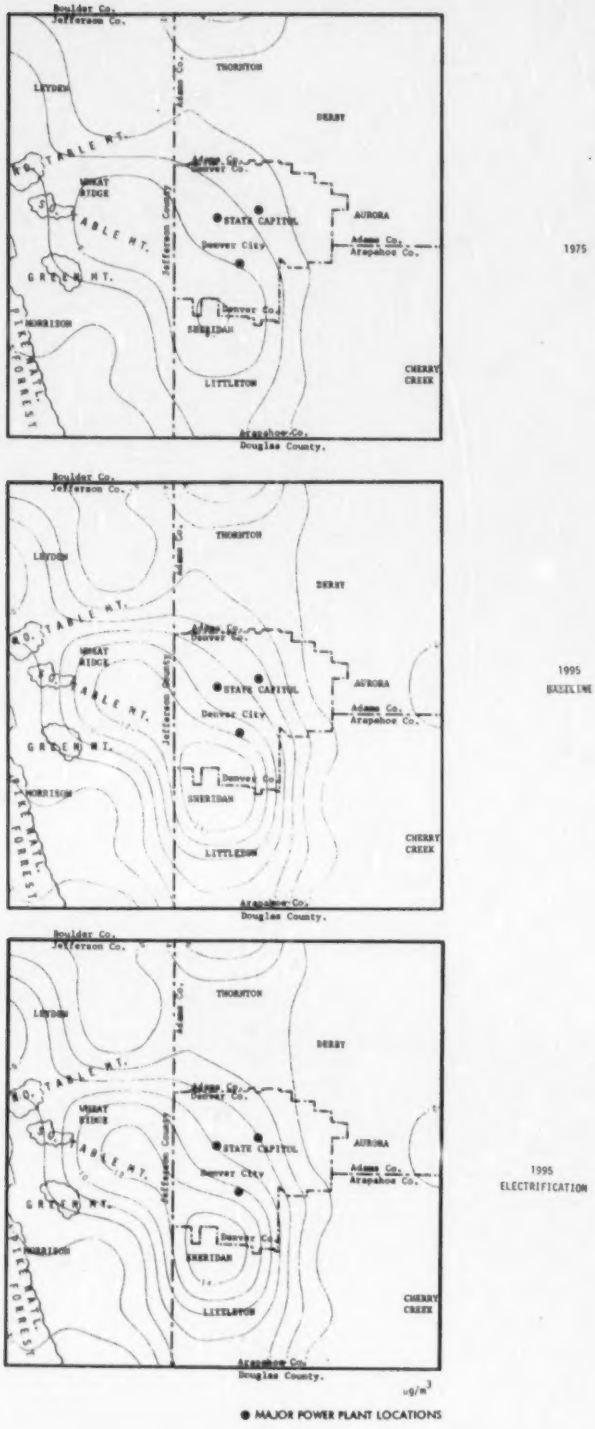


Figure 32. SO_2 Air Quality Isopleths for Denver

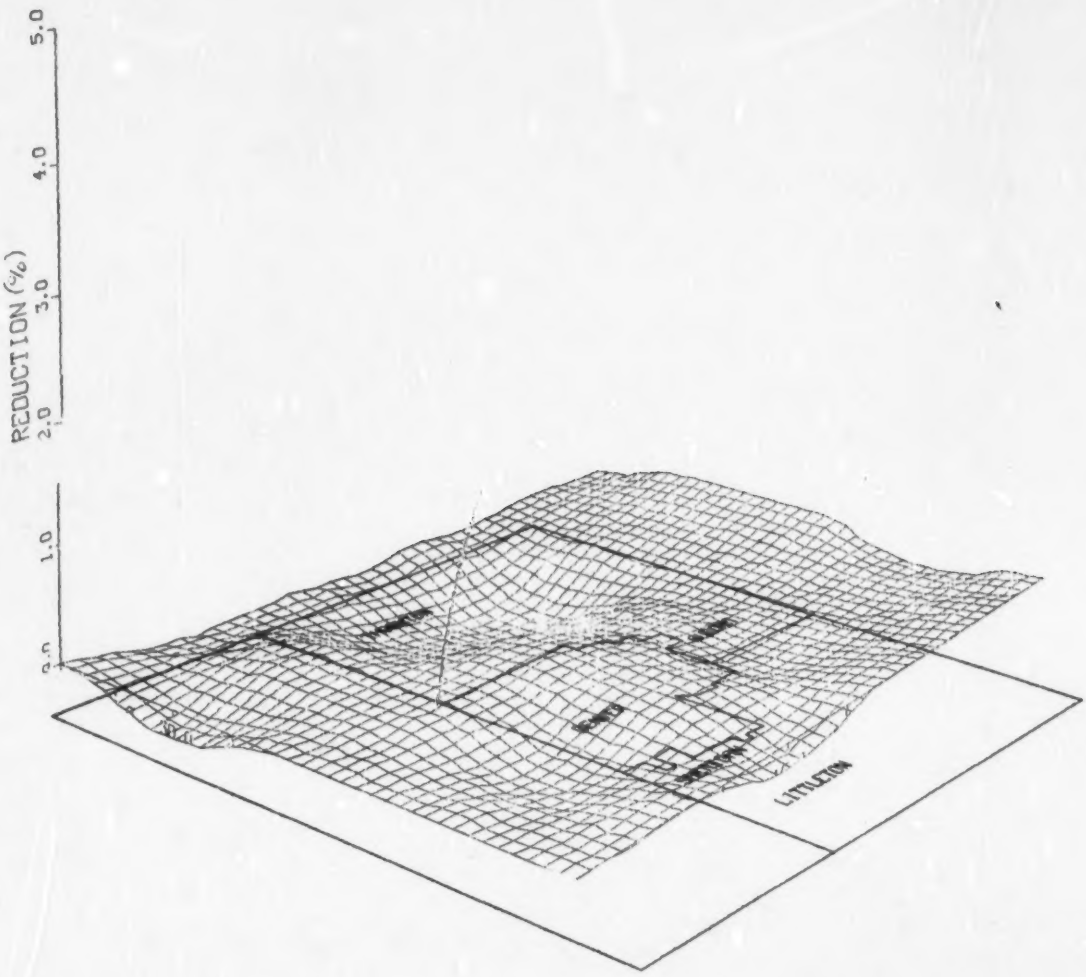


Figure 33

Relative SO_2 Air Quality in Denver - 1995
(Electrification - Baseline)

patterns remain similar. The effect of electrification on air quality is negligible as indicated in Figures 34, 35 and 36.

Particulates

Particulate concentrations, primarily centered about the high VMT downtown Los Angeles area, increase slightly in the baseline 1995 case, Figure 37. The air quality pattern remains similar to 1975. A dramatic change in particulate air quality is achieved by electrification, Figure 38. This is due to the initial high contribution of mobile emission sources and the replacement of these sources by electric cars.

Slight increases in particulate concentrations result in the baseline 1995 case for both Denver and St. Louis with no significant changes in air quality spatial patterns. The importance of stationary sources in these two regions results in only modest improvements in air quality due to electrification, (see Figures 39 through 42.) The regionwide average air quality for each of the regions is presented in Figure 43.

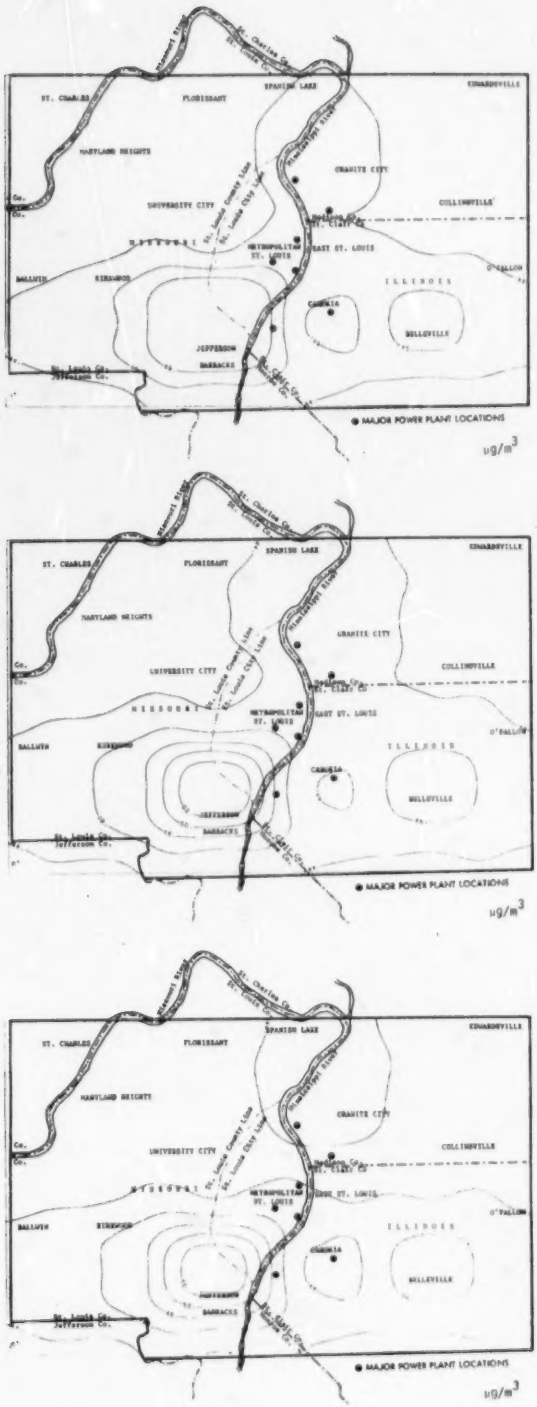


Figure 34. SO_2 Air Quality Isopleths for St. Louis

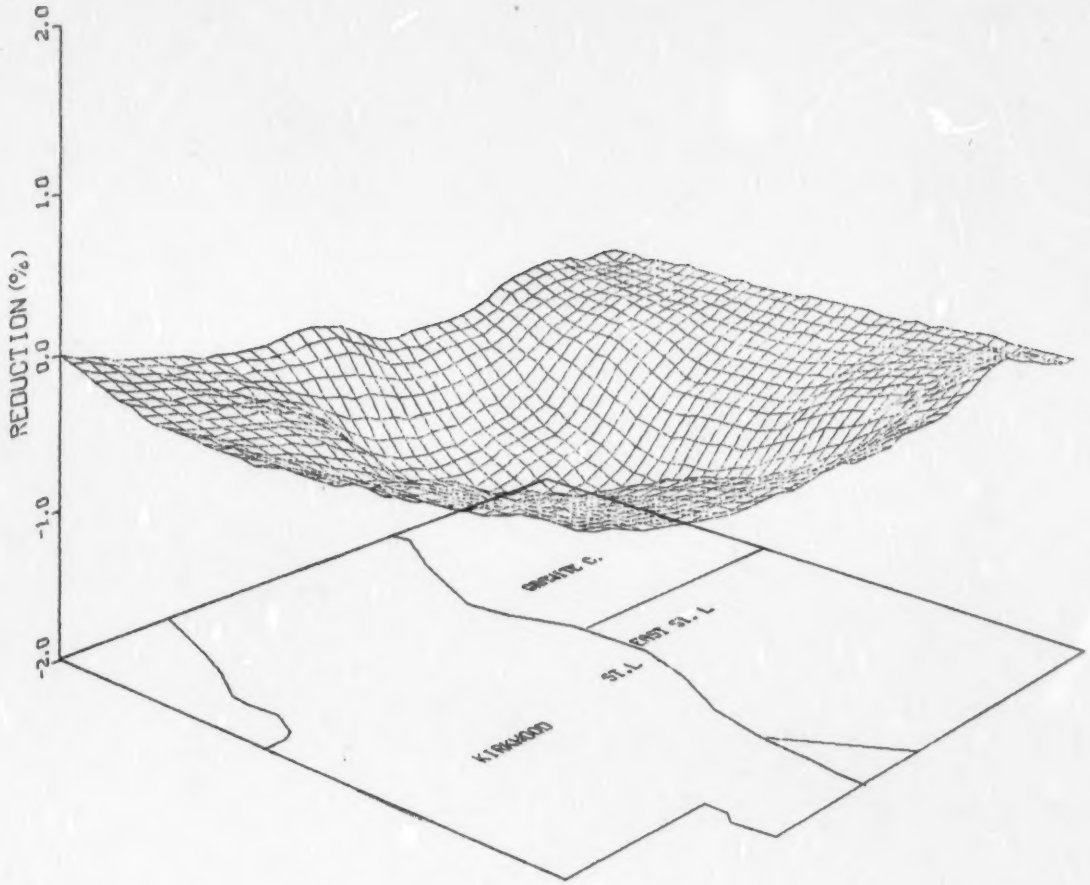


Figure 35

Relative SO_2 Air Quality in St. Louis - 1995
(Electrification - Baseline)

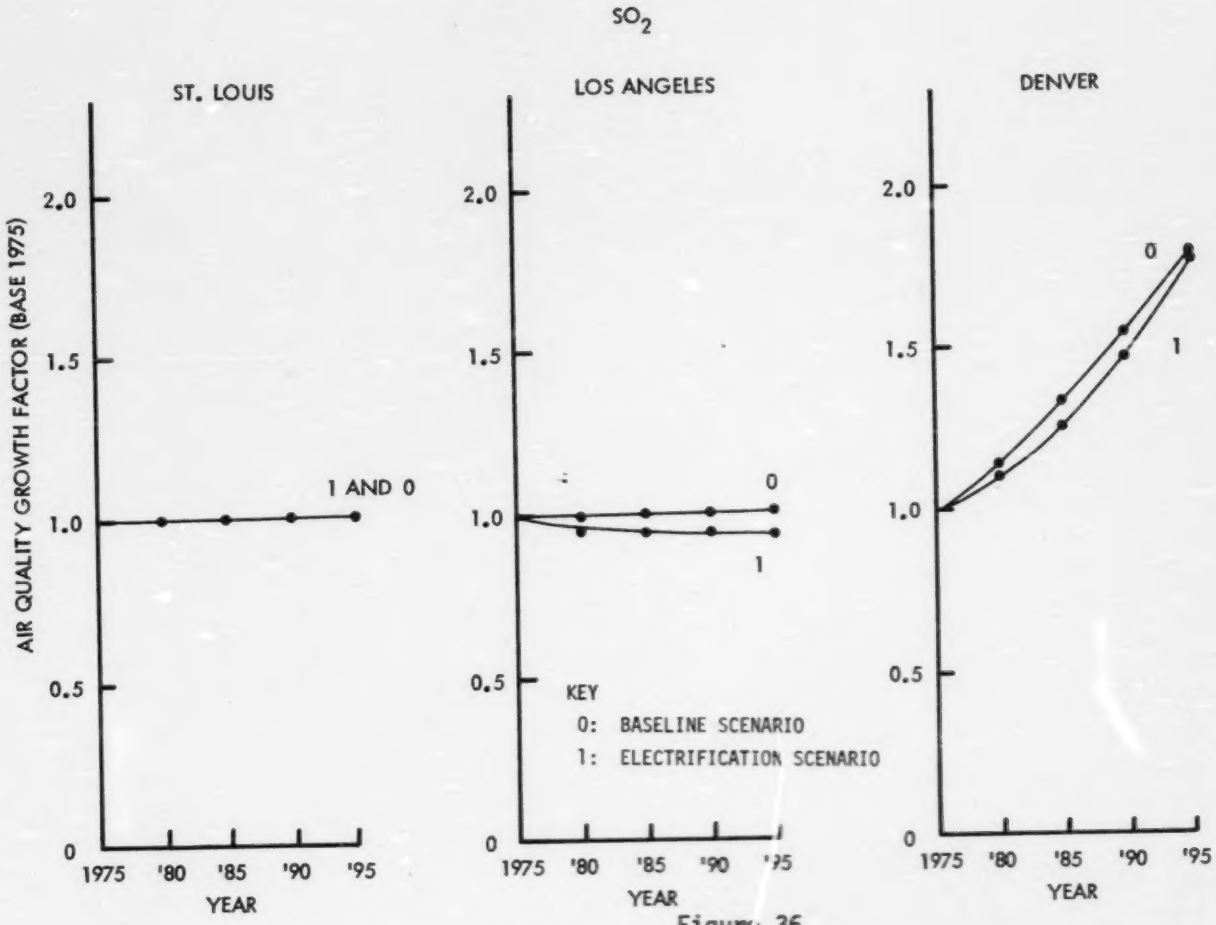
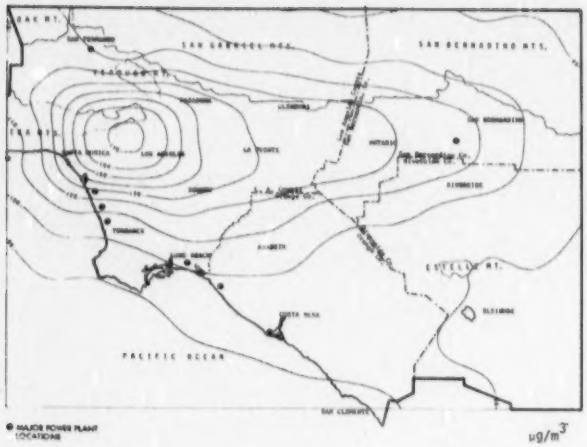
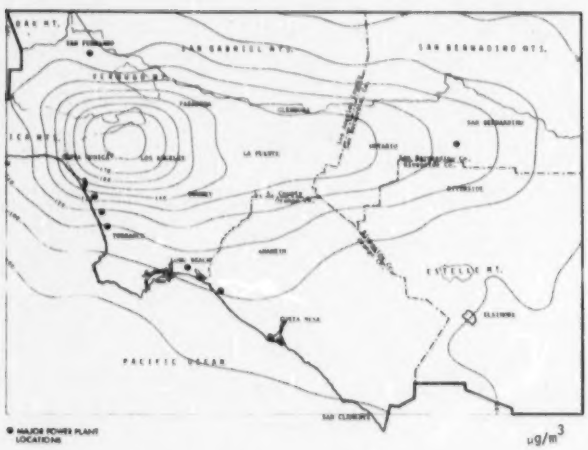


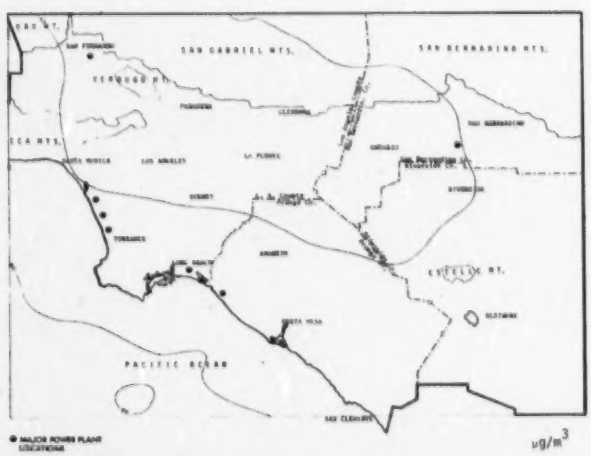
Figure 36
Variations in SO_2 Average Air Quality



1975



1995
BASELINE



1995
ELECTRIFICATION

Figure 37. Particulate Air Quality Isopleths for Los Angeles

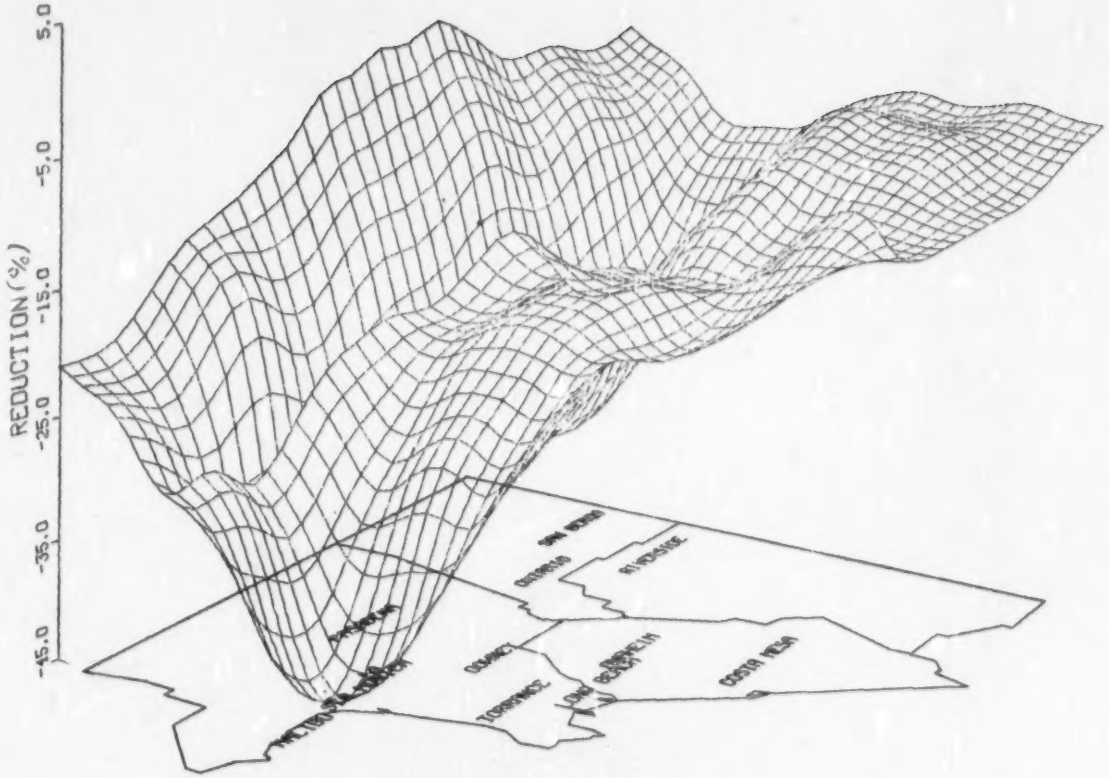


Figure 38

Relative Particulate Air Quality in Los Angeles - 1995
(Electrification - Baseline)

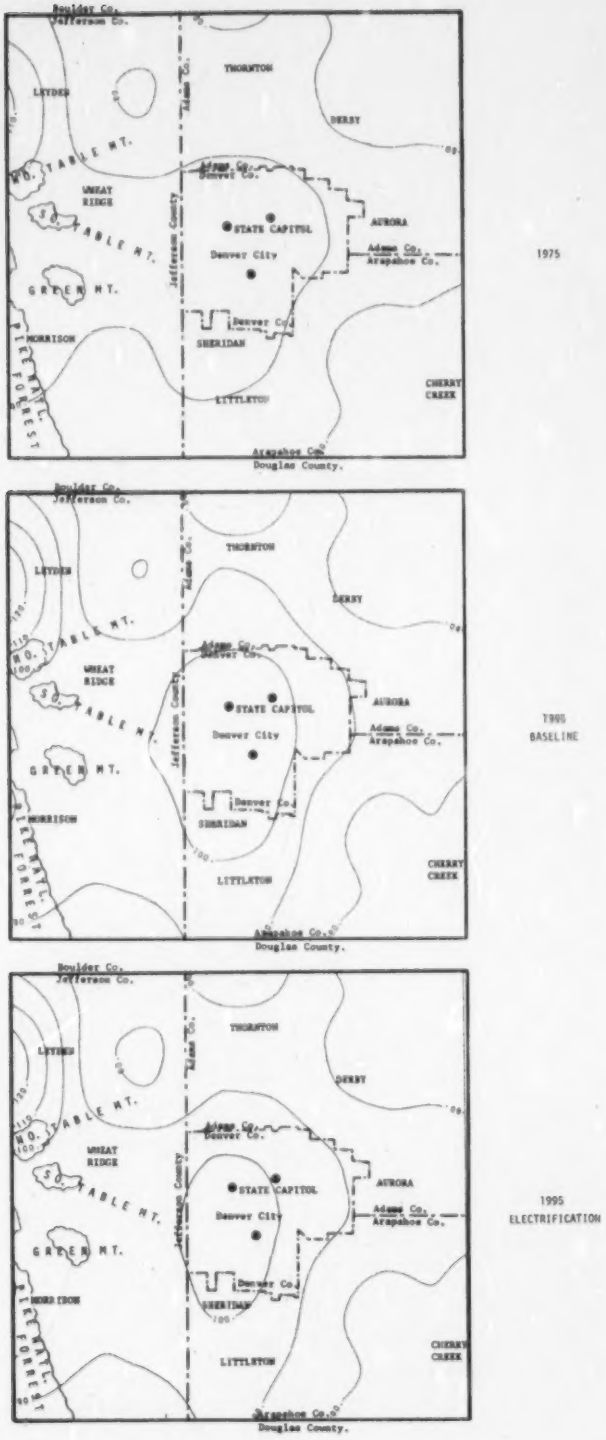


Figure 39. Particulate Air Quality Isopleths in Denver

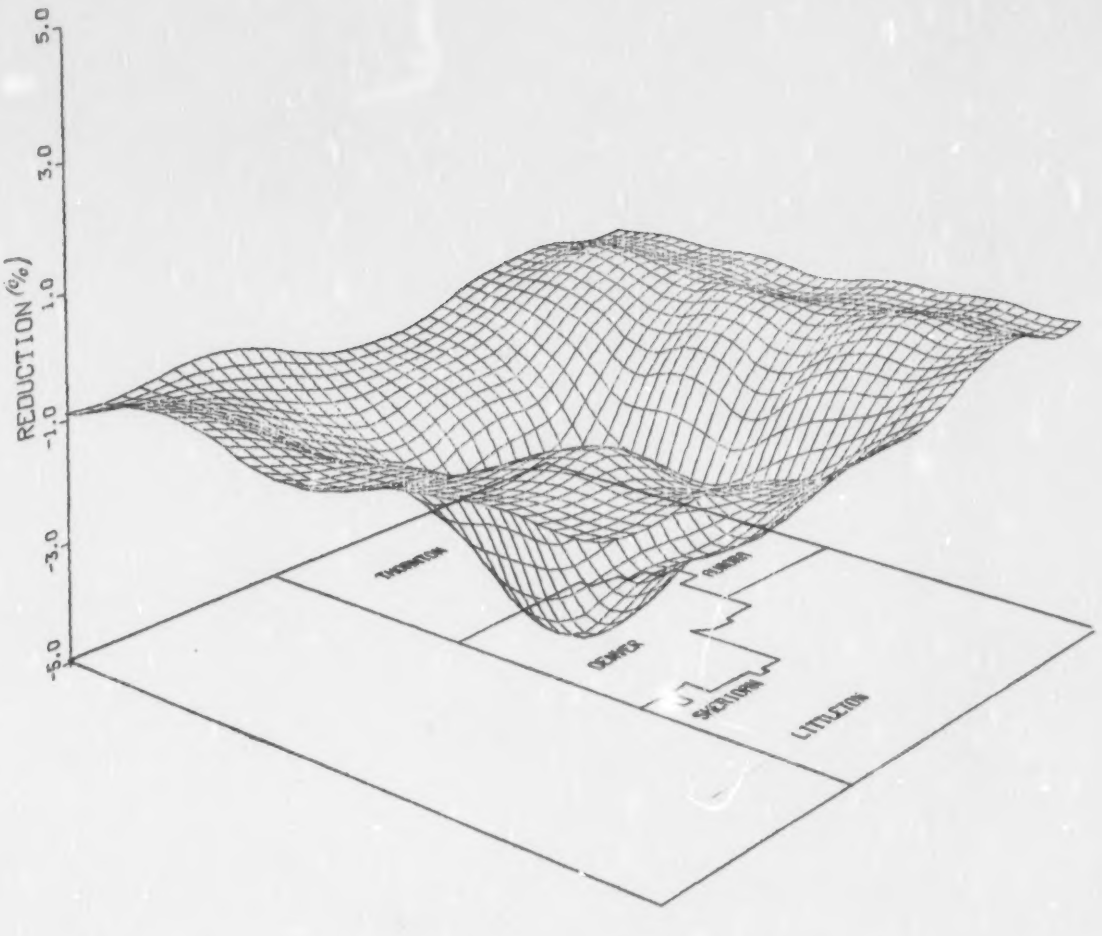
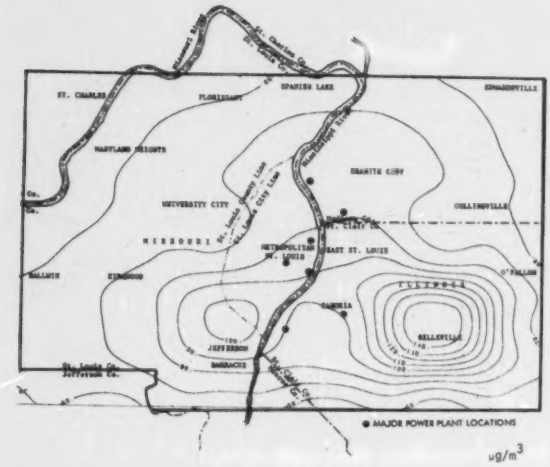
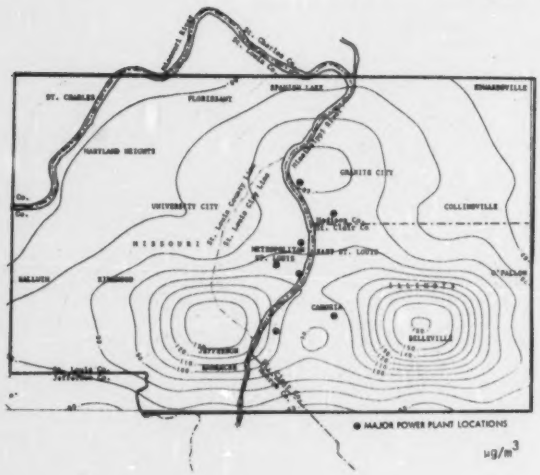


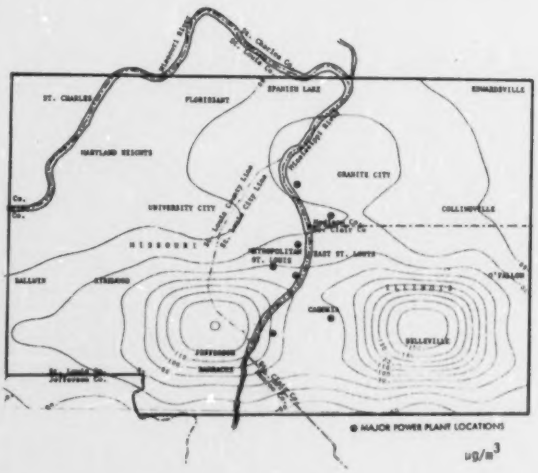
Figure 40
Relative Particulate Air Quality in Denver - 1995
(Electrification - Baseline)



1975



1995
BASELINE



1995
ELECTRIFICATION

Figure 41. Particulate Air Quality Isopleths In St. Louis

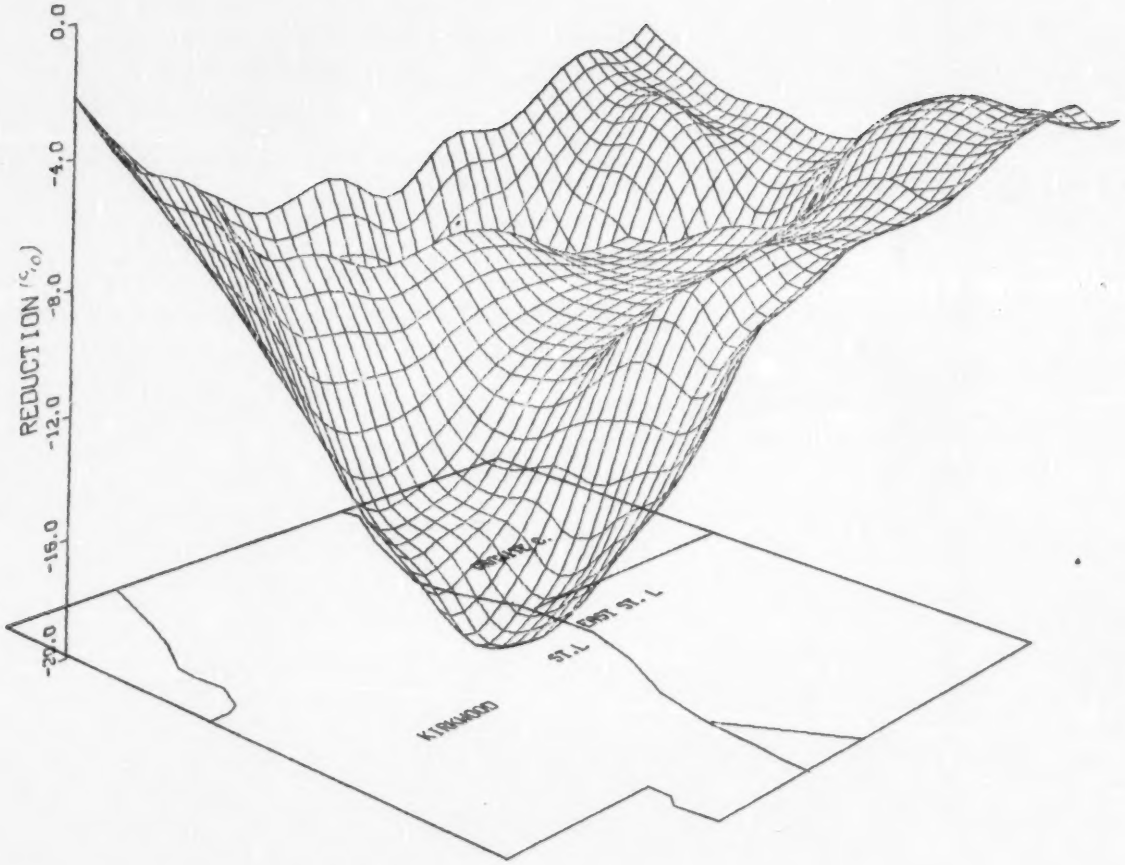
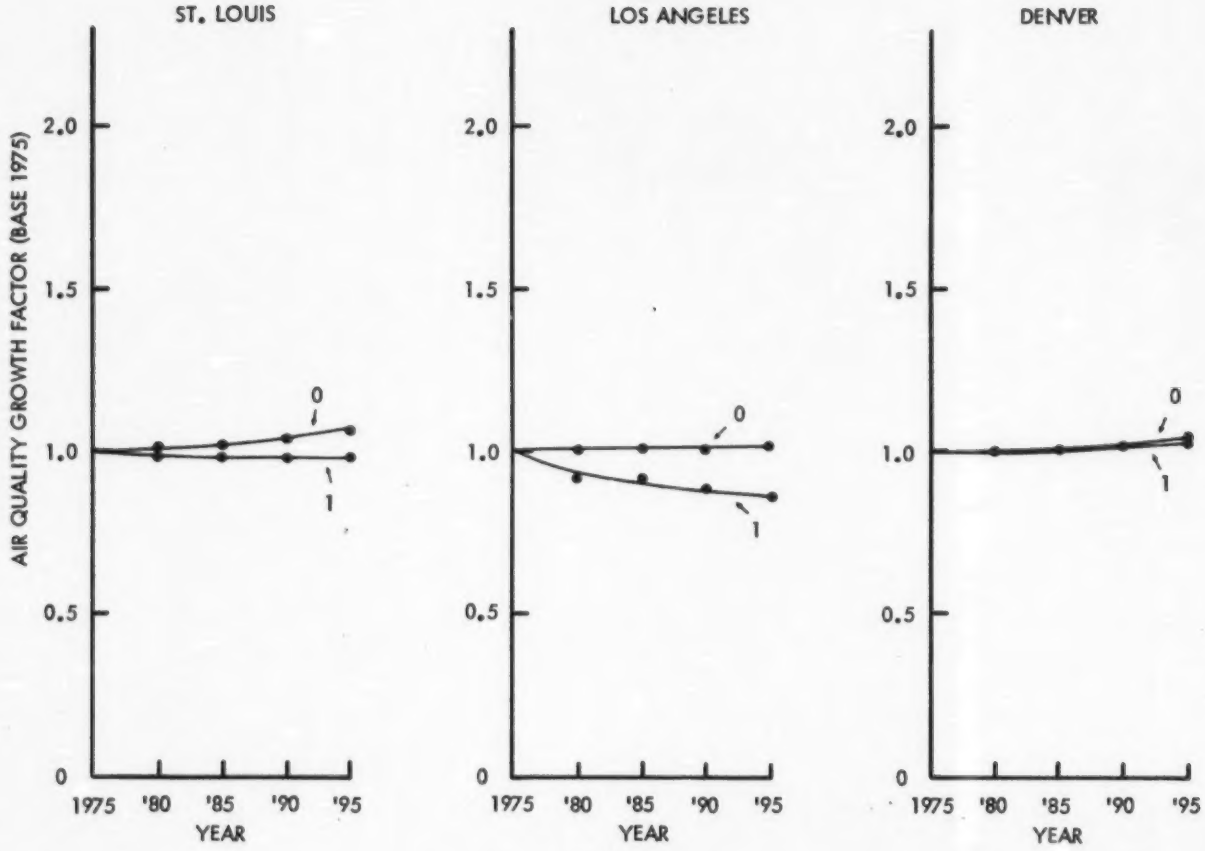


Figure 42

Relative Particulate Air Quality in St. Louis - 1995
(Electrification - Baseline)



PARTICULATE AIR QUALITY

Figure 43

Variations in Particulate Average Air Quality

SECTION VIII

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